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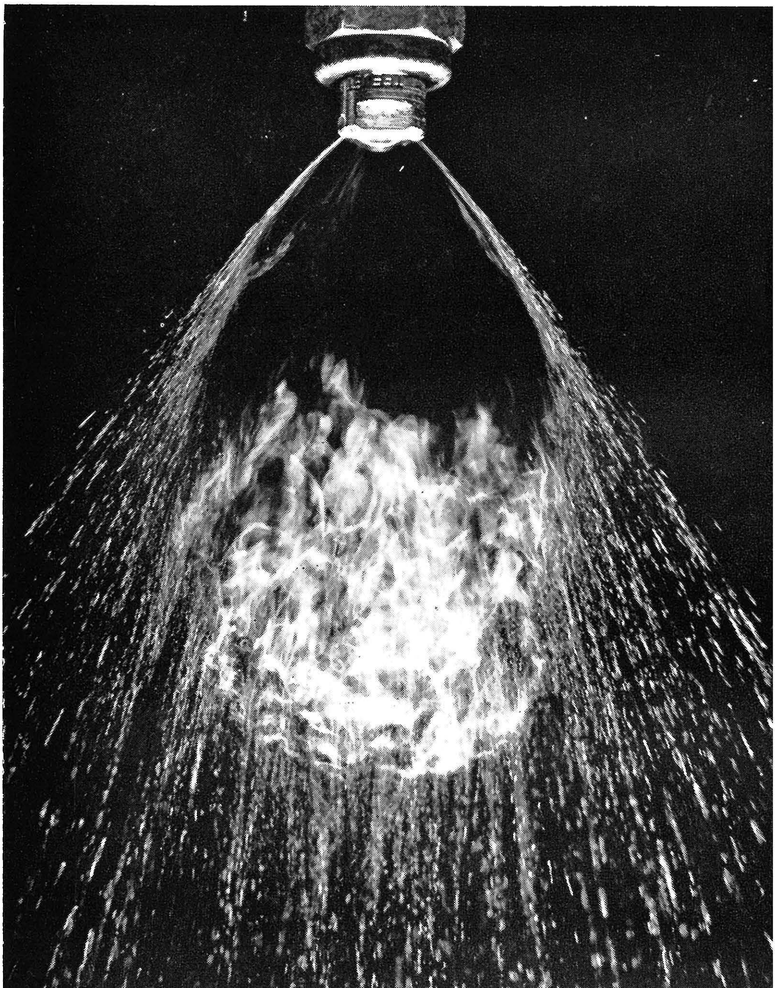

OHIO AGRICULTURAL EXPERIMENT STATION

WOOSTER, OHIO

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On the Cover: The flat spray pattern in this illustration shows the solid sheet of liquid as a black area directly below and on the central axis of the nozzle. This sheet or film of liquid breaks into filaments which shatter to droplets. These can be seen as short white streaks making a triangular pattern with the nozzle at the vertex. This portion of the spray droplet complex accomplishes the greater portion of spray deposition. In the center of the photograph is an area containing very small droplets so numerous as to present a smoke like appearance. This area is displaced from the central axis of the nozzle and is located in the near portion of the spray pattern. A similar area occurs symmetrically in the complex on the far side of the spray pattern.

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Spray Droplet Size As Related To Disease And Insect Control On Row Crops

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INTRODUCTION

Twenty-five years ago when row crops such as potato and tomato were being sprayed at application rates varying between 100 and 200 gallons per acre and at pump pressures from 300 to 400, or even 500 pounds per square inch (8, 10) there was less reason to be concerned about the size of the spray droplet than with gallonages only one-fourth to one-fifth as great, since the larger volumes and pressures afforded a much greater potential for leaf coverage. However, with the advent of low-gallonage, low-pressure spraying with spray formulations of higher concentration of the pesticide ingredient, in the late 1940's and early 1950's (13), the question of droplet size, as it might affect patterns of spray distribution and coverage of the leaf surface, began to assume added importance, especially insofar as the control of foliage diseases was concerned (15). As the application rate in terms of gallons per acre was decreased to 30, and even to 20 and 10 gallons in some instances (12), it became increasingly evident that smaller pumps operated at low pressures could be used in applying fungicidal and insecticidal spray formulations to row crops (12, 16) by this method.

It was during the latter interval (1948 - 1950) that the air-blast sprayer was introduced for the spraying of fruit trees (18), and shortly thereafter it was adapted to the spraying of row crops (17) by changing the position of the air outlets. Application rates of 30 to 40 gallons per acre are now most commonly used in spraying such crops as potato and tomato with this type of equipment.

In 1952, a series of experiments was initiated to study the possible effect of varying the size of spray droplets in spray application patterns on the control of diseases and insects on row crops (16). This was a cooperative effort between the departments of Botany and Plant Pathology, and of Zoology and Entomology of the Ohio Agricultural Experiment Statin and the Engineering Research Division, A.R.S., U.S. Department of Agriculture, now located at Wooster, Ohio. During the 10 years which this work has been carried on, over 20 separate experiments on the relationship between spray droplet size and disease and insect control have been completed.

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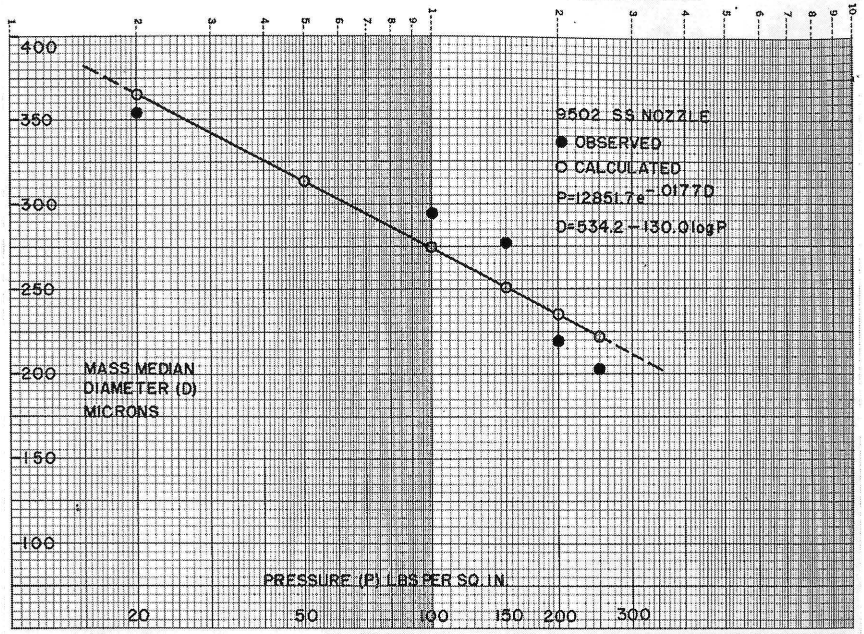

Fig. 1.—Graph showing relation between mass median diameter and pressure in the spray pattern of a 9502SS spray nozzle.

Procedure

The first three or four of these experiments, carried out in 1952 and 1953, dealt chiefly with variations in pressure and rates of application, as made with various types and sizes of nozzles mounted on fixed-boom hydraulic equipment (13, 14, 15). During the progress of these preliminary experiments laboratory tests were being made with a series of nozzle tips and discs operated at various pressures to determine the size of the spray droplets that were present in their spray patterns (4).

Spray nozzles of the type used in these experiments were operated under controlled laboratory conditions and samples were taken from the spray patterns produced. Measurements were made of the size and number of droplets collected. The "mass median diameter" of the drops in microns was calculated for each type of nozzle at several different operating pressures. This mass median diameter (referred to as MMD in this paper) represents a measurement which means that fifty percent of the volume of the spray is contained in drops of lesser diameter than the stated diameter, or conversely fifty percent of the spray volume is contained in drops of greater diameter than stated (2, 4, 7). For a given nozzle, mass median diameter and pressure were then related, as shown in Figure 1. These charts were used to select nozzles which would give the desired mass median diameter in their spray patterns and to determine the required operating pressure to secure the selected diameter. An example of the use of Figure 1, which is for a flat spray pattern from a 9502SS nozzle, is given below. Read up the left hand scale to 300 and across on this line to the right until the intersection with the plotted line is found. From this point read down to the pressure scale at the bottom of the graph. A pressure of 62 pounds per square inch is required with this type of nozzle to obtain a spray of the desired 300 microns mass median diameter. The observed data shows that mechanical differences in the nozzle tips can be expected to produce differences in droplet sizes, and because of this it is recognized that there are deviations in practice from the derived curve.

After selection of the droplet size and operating pressure the rate of spray delivery in gallons per minute was accurately measured for the nozzles to be used in the experiment. When more than a single nozzle was to be used on the spray boom several were calibrated and nozzles giving as near the same delivery rate as possible at the desired pressure were chosen for the experimental applications. Finally, an operator's chart was prepared as shown in Figure 2. Referring to Plot No. 1 of this Figure it can be seen that a 9506SS nozzle was used to apply a spray of 450 microns mass median diameter. A pressure of 40 pounds per square

PLOT	MI. per	GEAR and		TURN		LBS	NOZZLE		GAL. per	CONC.
NO.	HR.	THROTTLE		CLOSE	OPEN	PSI	SIZE	TYPE	ACRE	X
1	2.7	2	7	S-S-R-L-R	R-R-R	40	9506 SS	FLAT	35	3.0
2	2.7	2	6	S-S-R-R-L	R-R-R	76	9504 SS	"	"	"
3	2.0	2	5	L-S-R-R-S	R-R-L	167	9502 SS	"	"	"
4	2.8	2	8	R-S-R-R-S	L-R-R	192	9503 SS	"	"	"
5	3.6	3	7	S-R-L-S-L	L-R-R	250	"	"	"	"
6	3.4	3	6	S-L-R-S-L	L-R-L	76	D7-C25HSS	HC	35	3.0
7	1.3	1	6	L-R-L-S-S	L-R-L	24	D5-C25 HSS	"	"	"
8	1.6	1	7	S-L-R_4-S-L	L-R-L	65	D4-C25 HSS	" .	"	"
9	3.1	2	9	L-L-R_3-S-S	R-L-R	250	" "	"	"	"
10	2.8	2	8	L-S-L-L-S	L-L-R	65	D4-C25HSS	HC	20	5.3
11	2.4	1	15	S_{10}-L-R_2-S-R	R-L-L	98	D5-C25HSS	"	40	2.7
12	1.6	1	7	S_1-R-R-R_{14}-S	L-L-L	"	" "	"	60	1.8
13	1.2	1	6	S_4-R-L-R_2-S	R-L-R	"	" "	"	80	1.3
14	1.2	1	6	S_7-L-L_{10}-S-L	L-L-L	195	D7-C25HSS	HC	160	0.7
15	NO TREATMENT									

Fig. 2.—Typical operators guide chart for spray plot applications.

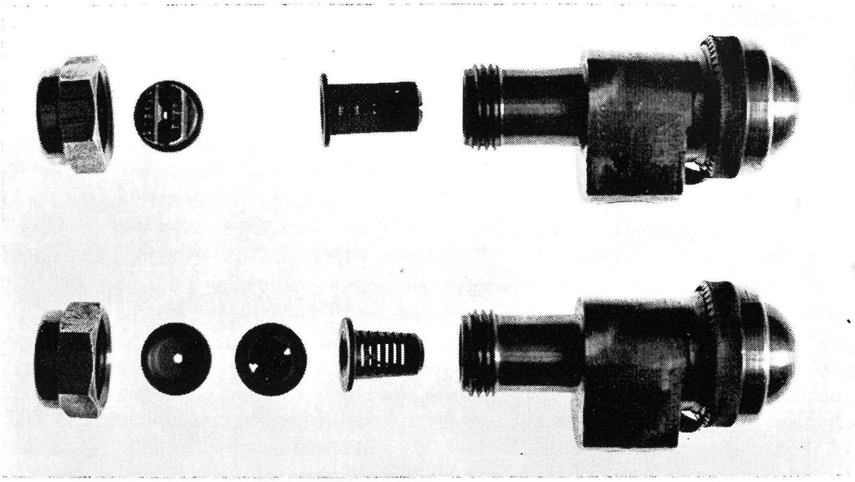

Fig. 3.—Disassembled parts of spray nozzles. Top, forms a flat type spray pattern: bottom, forms a hollow-cone type spray pattern.

inch was required. Average delivery of the two nozzles used was 0.526 gallons per minute at the desired pressure. An application rate of 35 gallons per acre was to be applied. The tractor speed to deliver this application from a two-nozzle boom on a 66-inch row was calculated to be 2.7 miles per hour. This speed was obtained by trials of the sprayer in the field and was obtained with the tractor in second gear and the calibrated throttle sector set at the seventh notch. All of these items were assembled in an operating chart for the tractor driver to use in the field application. Any minor adjustment in speed could always be made during the spray application to hold pressure and speed constant at desired values for as precise an application as possible.

The nozzles used produced spray complexes consisting of large numbers of droplets of many sizes. These ranged from less than one micron (0.00004 inch) to over 1200 microns (0.04724 inch) in diameter depending upon the design of the nozzle and the operating conditions. The very small drops make up the greater portion of the droplet complex (4). This is illustrated in Table 1-A, which shows that at least 95 percent of the drops collected were under 100 microns in diameter at any of the five operating pressures, for the nozzle used. The largest drop collected in any spray pattern from this nozzle, was 750 microns (0.02953 inch) in diameter and in every case at least half the volume of spray liquid was contained in drops over 200 microns (0.00787 inch) in diameter (indicated by MMD). Drops of this size, it will be noted, were never numerous enough to make up as much as two percent of the total number of drops in the spray population.

The spray nozzles used in these experiments are types frequently used for agricultural spray applications and are a commercially available product regularly sold to the consumer public. They are shown disassembled in Figure 3. Their use in these experiments is not to be

Table 1A. Average numbers of droplets of various size ranges collected in samples from a 9502SS nozzle operated at several pressures.

	Pressure P.S.I.									
	20		100		150		200		250	
Drop size range MMD-Microns	Percent of total drops	Cumulation of all drops	Percent of total drops	Cumulation of all drops	Percent of total drops	Cumulation of all drops	Percent of total drops	Cumulation of all drops	Percent of total drops	Cumulation of all drops
0- 20	94.3	94.3	85.3	85.3	88.7	88.7	89.9	89.9	93.7	93.7
21-100	3.4	97.7	10.2	95.5	8.9	97.6	8.4	98.3	4.8	98.5
101-200	1.4	99.1	2.9	98.4	1.6	99.2	1.2	99.5	1.2	99.7
201-300	.3	99.4	.9	99.3	.6	99.8	.4+	99.9+	.2+	99.9+
301-750	.6	100.0	.7	100.0	.2	100.0	.1−	100.0	.1−	100.0
MMD of samples in microns	354		294		277		220		200	
Diam. of largest droplet collected in microns	560		580		580		750		690	
Droplets desposited per sq. in. of sample	4622		15765		27143		24405		42559	

Fig. 4.—Application of a controlled drop-size spray to tomatoes.

considered an endorsement or recommendation for the use of these products. The numbers used in designating sizes have a particular meaning based on performance with water at an operating pressure of 40 pounds per square inch. The 9503SS flat spray tip is an example. The first two numbers indicate the included angle of the spray in the direction of greatest width is 95° when operated at the above pressure. The next two numbers show the delivery rate under these conditions is 0.03 gallons per minute and finally the letters SS show the nozzle tip is made of stainless steel. If there were no letters a brass tip would be indicated. The top nozzle in Figure 3 is a type as described above.

The lower nozzle shown in Figure 3 is a disc-type nozzle also frequently referred to as the hollow-cone type nozzle because of the shape of its spray pattern. There are two parts instead of a single tip which form the spray pattern from this nozzle. These are referred to as the disc and the core. The discs are of hardened stainless steel and have a single central hole in them. The cores are of brass or hardened stainless steel and are manufactured in different capacities which are simply designated by numbers. All parts are interchangeable and a wide variety of combinations of various capacities and angular spread are thus made available. A D7 C25HSS nozzle of this type would thus indicate a nozzle with a disc opening of 7/64 inch and a number 25 hardened stainless steel core. Amounts of spray delivered by the various combinations at different pressures as well as spray angles to be expected are indicated in tables provided by the manufacturer.

Fig. 5.—Application of controlled drop-size spray to sugar beets.

The graphs and charts described — made it possible to plan a series of treatments in which the size of the spray droplet could be varied by chosen increments, usually of 100 microns each, from 100 to 500 microns mass median diameter. The desired application rates, in terms of gallons per acre, could then be obtained by varying the speed of the tractor on which the sprayer assembly was mounted.

Some of the experiments in this droplet size series involved spray applications on potatoes, others on tomatoes, and one each on eggplant, cabbage and sugar beet. At least four and in some instances six replicates were used for each of the treatments included in each experiment. The sprays were mostly applied with one-row, tractor-mounted equipment, as shown in Figure 4. The tractor, the tread of which was usually set at 66 inches center to center of 11-inch tires, was equipped with a speedometer, and the throttle was calibrated on a scale or sector on which settings could be made to obtain the required forward speeds. Applications were made in virtually all instances with nozzles that formed flat or hollow-cone spray patterns. The two types used were those shown in Figure 3. One or two nozzles were used per row as the operating conditions required.

The potatoes were sprayed in 2-row plots, usually about 50 feet long, with the paired rows planted 34 inches apart. The tomatoes, in 10 to 12-plant plots, have been sprayed as single rows which were usually planted 66 to 72 inches apart. Eggplant and cabbage were sprayed in 30 to 40-foot plots on the basis of one nozzle for each 32 inches of swath width. The sugar beets were sprayed in 4-row plots about 40 feet long with the rows spaced 32 inches apart. The nozzles for spraying beets were on a boom mounted on one side of the tractor as shown in Figure 5.

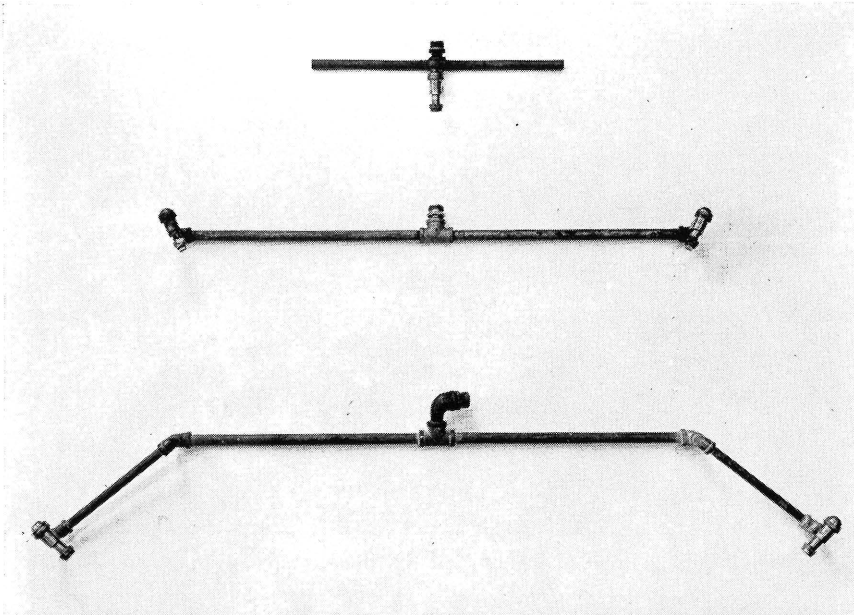

Fig. 6.—Boom assemblies used for different treatments.

The number of nozzles used per row varied with the crop being sprayed, and also with the application rate required to meet the specifications of a specific treatment. The potatoes, beets, and cabbage were sprayed in most instances with one nozzle per row. Two nozzles were usually used on each tomato row, since the "spread" of the plant was commonly too great to be covered by one nozzle. However, exceptions dictated by practical tractor speeds or selected application rates at specific drop sizes required in some instances that a crop such as potatoes might be sprayed with two nozzles per row (sometimes mounted in tandem), or that a tomato row might be treated with only one nozzle, as when the application rate was to be only 10 gallons per acre.

Complete boom assemblies were usually made up at the beginning of the season to meet specific application requirements, as illustrated in Figure 6, and these booms were then interchanged as the different treatments were to be applied. The plumbing assembly, with pressure indicators, relief valves, and other fittings, by means of which pressure changes were made and application was controlled, is shown schematically in Figure 7.

Conventional sprayer assemblies are usually equipped with a pressure gauge that registers 400 to 600 pounds per square inch and have relief valves that are capable of only rough adjustments especially at low pressures. Since it was necessary in these droplet-size experiments, to be able to select pressures as low as 20 to 25 pounds per square inch and to maintain pressures within narrow limits over the period of time required to spray several plot replicates, a sensitive relief valve and a pressure gauge calibrated in increments of only a few pounds were placed in a by-pass system where the pressure to the spray nozzles could be closely regulated. The elements of such a system as is shown graphically in Figure 7 can be identified in some detail in Figure 4.

The applications were mostly made at 10-day intervals and many were made at only one-half the recommended rate of pesticide dosage, since the use of a slightly too-long interval and a somewhat scanty use of the active control ingredient tended to permit a more definitive separation of treatments on the basis of their ability to control diseases and/or insects.

The foliage condition, or degree of defoliation, scores were made on a scale that varied from 0 to 10, with zero representing a complete loss of foliage, whereas 10 was the score used where no appreciable defoliation due to disease attack was present. Leafhopper counts were made from leaf samples selected at random from the different replicates of a given treatment, and flea beetle damage was determined by counting the feeding punctures in a number of leaves or leaflets selected in the same manner.

In a division of labor, made on a practical basis, spray applications were made by personnel of USDA Agricultural Engineering Research Division, and all disease and insect data were collected by personnel of the departments of Plant Pathology and Entomology, of the Ohio Agricultural Experiment Station.

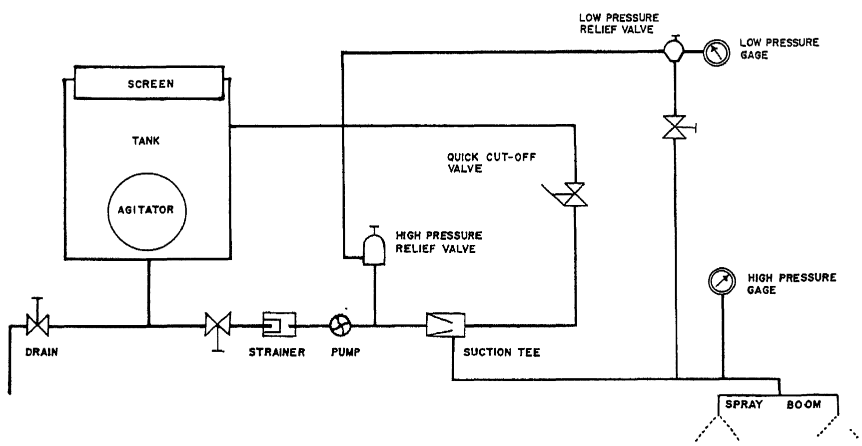

Fig. 7.—Schematic diagrams of quick-cutoff spray system used to prevent dripping between experimental plots.

Results — 1954

Data were obtained in 1952 and 1953 from treatments applied at various spray pressures. After a more positive relationship had been established between operating pressures and the mass median diameter of the droplets in the spray patterns, the range of sizes used did not seem to have been adequately covered at the spray pressures used, and therefore these data have been omitted.

In 1954, it was possible to interpolate the MMD droplet size values for most of the treatments that had been applied to potatoes. The data relative to that experiment are presented in Table 1.

In this experiment Irish Cobbler potatoes were sprayed with a mixture of maneb as the fungicide and a half and half mixture of DDT and dieldrin as the insecticidal ingredient at 10-day intervals. The diseases most likely to appear on potatoes in Ohio are early blight, *Alternaria solani* (Ellis & Martin) Jones & Grant, and late blight, *Phytophthora infestans* (Mont.) DuBary, and the insects are the potato leafhopper, *Empoasco fabae* (Harris), and the potato flea beetle, *Epitrix cucumeris* (Harris).

A special application of tribasic copper sulfate (Tribasic in this instance) was substituted in one spray application to afford an opportunity to determine the effect of different pressures and rates of water use on copper deposition and tenacity. Treatments 1 to 5 inclusive were designed to study the effect on disease and insect control of varying the pump pressure while the application rate was held constant. In Treatments 6 to 10 inclusive, the pressure was held constant while the gallonage was varied, and in Treatments 11 to 15 the gallonage and pressure were both held constant while the spray droplet size was varied by using nozzle apertures of different sizes. All of the first 15 treatments were applied with nozzles that delivered a flat spray pattern. Treatments 16 to 19 were applied in a hollow-cone pattern and involved gallonage variations from 20 to 160 gallons per acre.

Late blight was absent in the experiment and early blight was of no more than medium severity. Leafhoppers and flea beetles were of average incidence. Yield differences for the different treatments at harvest were not statistically significant at the 5 percent level.

As the pressure in Treatments 1 to 5 was varied from 200 to 20 p.s.i. the droplet size increased from 265 to 621 microns. Leafhopper control was perfect with all five treatments and there was no significant variation in the control of flea beetle damage. Neither was there any appreciable variation in early blight attack on the foliage (defoliation values). In treatments 6 to 10, where the gallonage was varied while the pressure was held constant, with little variation in droplet size, the control of leafhoppers was again 100 percent. There was some variation in flea beetle damage to the foliage in the differently treated plots, but since this was somewhat erratic in occurrence it was probably of little significance. Neither was there much variation in early blight incidence on the foliage. When the droplet size was varied from 379 to 621, while the pressure and gallonage were held constant (Treat-

Table 1. **Effect of variations in spray droplet size on disease and insect control on Cobbler potatoes and on the size and tenacity of copper deposits, at Wooster in 1954[1]. The fungicide-insecticide used was a mixture of Dithane M-22 and a mixture of DDT and dieldrin. Tribasic copper sulfate was applied in one instance to afford an opportunity to determine tenacity values.**

Treatment number	Droplet size in microns MMD	Pressure P.S.I.	Application rate G.P.A.	Nozzle numbers	Yield bu./acre	Potato leafhopper (nymphs per leaf)	Potato flea beetle (holes per leaflet)	Percent foliage dead	Copper deposit in $\mu g/cm^2$ on one side of leaf only: initial	Copper deposit: weathered	Percent adhesion after 10 days
1	265	200	40	9504	298	0	4.9	50	20.1	4.40	21.9
2	325	100	40	9504	284	0	3.0	53	20.6	4.71	22.9
3	385	80	40	9506	289	0	3.1	47	20.4	4.03	19.7
4	415	60	40	9506	289	0	4.5	51	22.2	4.97	22.4
5	505	20	40	9506	287	0	4.7	48	23.2	4.97	21.5
6	375	60	80	9508	284	0	3.3	47	16.0	3.11	19.6
7	375	60	60	9508	279	0	8.7	44	18.9	3.84	20.4
8	370	60	30	9504	283	0	4.3	39	19.2	3.54	18.4
9	260	60	20	9503	281	0	3.6	47	20.2	4.17	20.7
10	—	60	10	80015	287	0	7.4	42	20.0	3.99	19.9
11	379	40	40	9502	281	0	2.3	47	22.7	5.07	23.7
12	430	40	40	9503	282	0	7.2	52	20.1	4.49	22.3
13	479	40	40	9504	278	0	3.6	53	15.0	4.63	24.2
14	550	40	40	9506	287	0	3.3	42	21.7	4.03	18.6
15	621	40	40	9508	277	0	5.4	50	17.5	3.60	20.6
16	290	60	20	D5,C25	290	0	6.0	45	15.0	4.48	29.3
17	—	60	40	D8,C25	287	0	3.5	47	12.5	3.41	27.2
18	—	60	80	D10,C45	303	0	6.6	46	10.1	3.00	29.6
19	185	300	160	D5,C45	281	0	5.0	48	9.7	2.83	29.3
20	No treatment		—	—	269	7.2	46.2	67	—	—	—
LSD at 5 percent level					23						

[1]All plots were sprayed with 2 nozzles per row except Treatments 11 and 19. Nozzles paired in tandem on No. 11. Four nozzles per row used on Treatments 11 and 19.

ments 11 to 15), there was again little variation in the control of foliage damage by flea beetles and early blight, and leafhopper control was 100 percent with all treatments. When a hollow-cone pattern was used to apply 20, 40, and 80 gallons per acre of spray, all at 60 p.s.i., the control of leafhoppers was 100 percent and the average control of flea beetles and early blight was approximately equal to that obtained with 160 gallons applied at 300 p.s.i.

Thus, this experiment demonstrated that a fungicide-insecticide formulation may give a similar degree of disease and insect control when applied over a wide range of pressure and gallonage rates and spray droplet sizes. Also, that it may make little difference whether the spray pattern is fan shaped (flat) or in the form of a hollow cone.

A fixed copper (Tribasic) was substituted for Dithane M-22 in one of the spray applications so that the effect of varying the MMD of the spray droplet and the quantity of water used in making the application and retention of copper might be determined. The data obtained are given in the last two columns of Table I. Deposition and retention varied but little in Treatments 1 to 5 where the droplet size was varied from 265 to 505 microns while the gallonage was held constant. When this situation was reversed in Treatments 6 to 10 by varying the gallonage while a constant pressure was maintained, the deposition showed some tendency to increase with a decrease in gallonage, whereas the percentage of adhesion varied little, if any. Treatments 11 to 15, where the droplet size was varied by using different nozzle apertures while the pressure and gallonage were held constant, showed the highest average deposition and adhesion values. The four applications made with a hollow-cone spray pattern (Treatments 16 to 19) showed a tendency toward slightly lower deposition values but higher percentages of adhesion than did the corresponding gallonage applied in a flat spray pattern.

1955

Additional experiments on the influence of pressure gallonage, and droplet size variations on disease control on potatoes and tomatoes were carried on in 1955. Twelve treatments were applied to Cobbler potatoes in one of the experiments, the data for which are given in Table 2. In Treatments 1, 2, and 3 the pressure and application rates were held constant and the droplet size was varied by changing flat-spray nozzle tips. Hollow-cone nozzles were substituted under the same conditions of pressure and gallonage in Treatments 4 and 5. In Treatments 6, 7, and 8 the droplet size was varied by using different pressures while gallonage and the nozzle tip were held constant. Three different droplet sizes were obtained in Treatments 9, 10, and 11 by using different flat-spray nozzle tips, while the pressure was held constant. Treatment 12 was a control check at a higher gallonage than was used in any of the first eleven treatments. Treatment 13 was an untreated check

Late blight did not appear in this experiment and early blight was of only medium severity. The fungicide-insecticide formulation, which consisted of Dithane M-22 and a 1 to 1 mixture of DDT and dieldrin,

Table 2. Spray droplet-size variations and the control of early blight on Cobbler potatoes at Wooster, 1955. Dithane M-22 at 1.5 pounds per acre was the fungicide used.

Treatment number	Droplet size in microns MMD	Pressure P S I	Application rate G P A	Nozzle numbers	Yield bu./acre	Percent foliage dead
1	344	40	35	9502	526	52
2	411	40	35	9504	545	54
3	426	40	35	9508	508	56
4	289	40	35	D4,C25	550	50
5	387	40	35	D10,C25	537	50
6	345	30	35	9503	519	54
7	244	70	35	9503	568	51
8	113	250	35	9503	534	51
9	233	40	10	95015	534	60
10	344	40	20	9502	573	54
11	488	40	60	9510	556	52
12	488	40	80	9510	498	55
13	No treatment	—	—	—	498	64
LSD at 5 percent level					42	

was applied at 10-day intervals. The yields of the sprayed plots were significant statistically above those of the unsprayed check in only five of the twelve treatments used, and only four of eleven treatments produced yields significantly larger than the low for the group found in Treatment 3, where a pump pressure of 40 p.s.i. was accompanied by a comparatively large droplet size (426 microns).

In treatments 1, 2, and 3 a variation in droplet size, obtained by changing nozzle tips, had no significant effect on yield, but there was a very slight increase in defoliation with an increase in droplet size. When a hollow-cone pattern was substituted in Treatments 4 and 5 there was again little change in the results obtained. Changes in pressure were employed in Treatments 6, 7, and 8 to vary the droplet size and in this series the largest mass median diameter (Treatment 6) gave slightly poorer results than did the sprays of smaller drop size.

When the MMD was varied by using different nozzle tips and the spray was applied at different rates (Treatments 9, 10, 11) gallonage seemed to have a greater effect in determining the degree of disease control than did droplet size. Thus, if Treatment 9 (233 MMD and 10 g.p.a.) is compared to Treatment 7 (244 MMD and 35 g.p.a.) the former did not do as well in checking defoliation as did the latter. However, an increase in the application rate to 80 gallons per acre (Treatment 12) did no better than 60 gallons (Treatment 11), although these two treatments were applied at the same MMD.

Thus, in summary, the results obtained in this experiment further strengthens the observation made in connection with the 1954 experiment that, when disease (early blight) is of only medium severity, there is little difference in the degree of control obtained by large variations in spray-droplet size as they are brought about by changes in spray pressure or nozzle characteristics.

In another 1955 experiment on potatoes a series of MMD variations was used to observe their comparative effectiveness in the control of leafhopper and flea beetle damage. All treatments were applied at comparatively low gallonages (10 to 35 gallons of water per acre) while the MMD values ranged from 100 to 500 microns, in a series of 12 treatments. The insecticidal formulation used consisted of a half and half mixture of wettable powders of DDT and dieldrin which was used at 1.5 pounds per acre in 10-day applications. Dithane Z-78, at 3 pounds per acre, was used as the fungicide. The results obtained are given in Table 3.

In Treatments 1 and 2 the droplet size was varied by using two different sizes of flat-spray nozzle tips, while pressure and gallonage were held constant. In Treatments 3, 4, and 5 the same procedure was followed by changing the size of the hollow-cone nozzle parts. Droplet size variations accompanied changes in pressure while the gallonage and the size of flat-spray nozzle tips were being held constant in Treatments 6, 7, and 8. The same procedure was followed in Treaments 9, 10, and 11 with hollow-cone spray patterns. In Treatment 12 a spray of small MMD value was obtained by using a small nozzle tip at a pressure of 200 p.s.i. Treatment 13 was an untreated check.

Flea beetle damage was comparatively severe in the check plots, as was that from leafhoppers. As a result the check yield was greatly reduced, and was significantly (statistically) less than those of the treated plots in every instance.

All of the spray treatments gave 100 percent control of leafhoppers, which indicates that wide variations in droplet size do not alter the effectiveness of a DDT spray formulation in the control of that pest. There was some variation in the degree of leaf feeding by adult flea beetles, but even this was greatly reduced below that in the untreated check plots by all of the treatments used.

In Treatments 1 and 2 there was little difference in flea beetle feeding, but in Treatments 3, 4, and 5 the one with the smallest droplet size (Number 3) gave somewhat the best result. When the MMD values in flat spray patterns were varied by changing the pressure with the nozzle size constant, as in Treatments 6, 7, and 8, the reduction in feeding was greatest with the largest droplet size as produced at a low pressure. However, when the same changes were made with hollow-cone spray patterns (Treatments 9, 10, and 11) there was little effect on flea beetle damage to the foliage. When the volume of the spray formulation was dropped to 10 gallons per acre (Treatment 12), there was a reduction in flea beetle control, which was substantially below that in Treatments 8 and 11 where small MMD's were used. This indicates again, as with disease control, that when a spray volume as low as 10 gallons per acre is used, an appreciable reduction in control below that obtained at higher gallonages will occur.

Table 3. Spray droplet-size variations and the control of leafhoppers and flea beetles on Cobbler potatoes at Wooster, 1955. The insecticide used was a 1 to 1 mixture of DDT and dieldrin applied at 1 pound per acre.

Treatment number	Droplet size in microns MMD	Pressure P.S.I.	Application rate G.P.A.	Nozzle numbers	Yield bu./acre	Potato leafhopper (nymphs per leaf)	Potato flea beetle (holes per leaflet)
1	352	30	35	9502	653	0	3.6
2	470	30	35	9508	625	0	3.7
3	350	30	35	D6,C25	673	0	2.7
4	410	30	35	D10,C25	666	0	4.5
5	500	30	35	D16,C45	665	0	6.1
6	359	20	20	9502	629	0	2.6
7	322	70	20	9502	663	0	3.3
8	200	250	20	9502	630	0	5.1
9	274	20	20	D5,C23	625	0	5.6
10	216	70	20	D5,C23	646	0	5.8
11	133	250	20	D5,C23	677	0	4.6
12	101	200	10	9501	604	0	10.9
13	No treatment	—	—	—	455	17.8	62.3
LSD at 5 percent level					26		

The results obtained in this experiment indicate that a considerable variation in spray droplet size, as obtained by variations in pressure or changes in nozzle tips, may be made without greatly altering the degree of insect control obtained in the spraying of potatoes.

Another experiment in 1955, that involved variations in droplet size as developed by changes in pressure, and/or nozzle tips, was performed on tomatoes. Manzate was used as the fungicide. It was applied on a 10-day schedule at only 1.5 pounds per acre application (the recommended rate of use is 3.0 pounds) on the assumption that a lower than usual rate of use of the fungicide might make it easier to distinguish any differences in effectiveness in disease control by the different treatments. Anthracnose fruit rot (*Colletotrichum phomoides*) was of more than average severity, especially in the harvest of September 27, and it is on the basis of the percentage of fruits affected on that date that the treatments used can best be evaluated. Early blight was also rather severe late in the season and it had caused a considerable degree of defoliation by October 1. The data obtained on disease control in this experiment are given in Table 4.

Droplet size varied only slightly in Treatments 1, 2, and 3, where the tip sizes of flat-spray nozzles were changed, while pressure and application rate were held constant. Three droplet sizes were obtained by the use of different hollow-cone nozzle discs in Treatments 4, 5, and 14. In Treatments 6, 7, and 8 the application rate was held constant and the droplet size was varied by changing the pressure used with flat-spray nozzles of one size. In Treaments 9, 10, 11, 12, and 13 the pressure was held constant at 40 p.s.i., while the gallonage was varied from 10 to 160 gallons per acre by changing the tips of flat spray nozzles and also by changing the tractor speed used while applying the different

Table 4. The effect of varying the spray droplet size-volume relationships of fungicide applications on disease control on tomato at Apple Creek, 1955. Manzate at 1.5 pounds per acre was the fungicide used.

Treatment number	Droplet size in microns MMD	Pressure P.S.I.	Application rate G.P.A.	Nozzle numbers	Net yield marketable fruit tons/acre	Percent culls	Percent Anthracnose on fruit on, — Sept 27 harvest only	Percent Anthracnose on fruit on, — All harvests	Percent foliage dead on Oct. 1	Green fruit at end of season tons/acre
1	344	40	35	9502	18.1	15.1	5.8	5.4	48	7.5
2	411	40	35	9504	18.6	13.4	7.4	5.2	46	5.0
3	426	40	35	9508	17.5	10.4	6.1	4.5	35	7.7
4	289	40	35	D4,C25	20.4	13.0	5.5	4.2	41	6.5
5	387	40	35	D10,C25	17.1	17.0	11.9	6.8	48	4.9
6	345	30	35	9503	20.6	14.0	8.0	6.2	48	5.3
7	244	70	35	9503	18.2	10.3	6.2	5.2	45	6.2
8	113	250	35	9503	18.7	13.1	5.0	4.5	45	4.7
9	233	40	10	95015	19.7	12.6	11.0	6.5	60	3.4
10	344	40	20	9502	19.7	10.2	6.0	4.3	43	5.4
11	488	40	60	9510	17.0	11.1	4.8	4.1	28	8.9
12	488	40	80	9510	20.2	10.3	3.5	3.6	29	7.2
13	488	40	160	9510	19.0	12.5	6.9	4.9	36	8.1
14	132	250	35	D4,C25	22.3	11.8	4.5	4.0	39	7.4
15	150	250	160	9504	17.7	10.9	2.6	2.5	34	7.1
16	No treatment		—	—	17.6	21.5	23.1	10.3	70	3.6

Note: Two nozzles were used in spraying each tomato row (a space 64″ wide).

treatments. Droplet sizes were varied in Treatments 9, 10, and 11, where nozzle tips of different aperture sizes were used. Treatments 13 and 15 represented sprayed checks where 160 gallons per acre were applied at two MMD's. Treatment 16 was an unsprayed check.

In Treatments 1, 2, and 3, where pressure and application rate were held constant and the mass median diameter increased by using an increasingly larger tip aperture in a flat-spray nozzle, the largest drop size (Treatment 3) gave the best control of fruit and foliage diseases, and the most green fruit at the end of season. However, the reverse was true with a hollow-cone pattern (Treaments 4 and 5) where the small droplets of Treatment 4 gave the better disease control. In Treatments 6, 7, and 8 where the spray droplet size was decreased by increasing the pressure, while the gallonage and flat nozzle tip size were held constant, disease control on fruit and foliage showed some tendency to decrease with a decrease in droplet size.

The most marked change in anthracnose and early blight control occurred in Treatments 9, 10, 11, 12, and 13 where the application rate was varied at constant pressure by changing the size of the nozzle aperture, or the tractor speed. In this series the use of a 10-gallon application rate was less effective than a 20-gallon rate (Treatment 9 vs. 10) in the control of both fruit-rot and defoliation, but there was also a difference in the MMD of these two spray applications. Treatments 11, 12, and 13 were applied at 60, 80, and 160 gallons per acre, respectively. Nozzle size, MMD, and pressure were all held constant. Fruit-rot control was best at the 80-gallon rate, and defoliation was about the same at 60 and 80 gallons per acre (Treatments 11 and 12). Total yields of green and ripe fruit increased steadily with the application rates up to 80 gallons per acre. Above that there was little change in total fruit yield. Thus, it would appear that the differences at low application rates (Treatments 9 and 10) were probably due to the low gallonage used rather than to differences in spray droplet sizes.

When two quite different pressures were used with hollow-cone nozzles in Treatments 14 and 4 to obtain different droplet sizes, the change in droplet size from 132 to 289 microns MMD brought about very little, if any, change in disease control. However, when a similar change was made with flat-spray nozzles (Treatments 6 and 8), the higher pressure and smaller droplet size of Treatment 8 gave the better control of anthracnose, with less change in defoliation and the percentage of green fruit at the end of the season.

Most of the data relative to the influence of changes in spray droplet size on disease control were conflicting in this experiment, and the differences in disease incidence seem to be more dependent on differences in application rate than on changes in the MMD of the spray drops.

1956

The experiments on the influence of spray droplet size on disease and insect control on potatoes and disease control on tomatoes were con-

Table 5. Spray droplet size and the control of potato diseases at Wooster, 1956. Parzate at 1.5 pounds per acre per application was used as the fungicide.

Treatment numbers	Droplet size in microns MMD	Pressure P.S.I.	Application rate G.P.A.	*Nozzle numbers	Yield bu./acre	Percent foliage dead
1	400	25	40	9503	540	48
2	300	45	40	9503	618	31
3	200	120	40	9503	599	31
4	100	277	40	9503	562	29
5	200	120	80	9503	594	29
6	300	95	40	9502	585	34
7	300	136	40	9504	614	32
8	300	72	40	D7,C25	594	39
9	400	50	40	9508	541	42
10	280	50	40	9503	569	42
11	No treatment	—	—	—	432	87
12	510	20	45	9508	592	34
13	488	40	45	9510	544	44
14	488	40	80	9510	568	34
LSD at 5 percent level					67	

*Flat spray pattern tips all stainless steel. Hollow cone spray pattern cores hardened stainless steel.

tinued in 1956. Thirteen variations in spray droplet sizes and application rates were compared and with an untreated check on Cobbler potatoes at Wooster. These and the data obtained on disease control and yield are given in Table 5. Early blight was comparatively severe during the last half of the growth period and a light infection of late blight also caused some defoliation. Parzate at 1.5 pounds per acre, half the usual rate, was used. The 2-row plots were sprayed with one nozzle placed over each row.

Droplet sizes in Treatments 1, 2, 3, and 4 were varied progressively downward by increasing the pressure while the application rate and the aperture size of the flat-spray nozzle were held constant. Treatment 5 was included to check the effect of doubling the application rate with the same nozzle tip and spray drop size as used in Treatment 3. In treatments 2, 6, 7, and 8 the application rate and droplet size were held constant while the pressure and nozzle tips (Treatment 8, delivered in a hollow-cone pattern) were varied. In Treatments 9 and 10 the same gallonages were applied while the droplet size was varied by using two different nozzle tips at constant pressure. A single application rate was used in Treatments 12 and 13, but the nozzle tips were varied, and in Treatment 14 the gallonage was doubled by utilizing a slower tractor speed than was used in applying Treatment 13, with the MMD and nozzle size left the same.

In the first four treatments listed in Table 5 all were applied with a 9503 nozzle at 40 gallons per acre and the variations in droplet size were obtained by varying the pressure. The degree of disease control obtained was similar for MMD values of 300, 200, and 100 microns.

The 400 micron application did not do as well as the others in this group. Treatment 2 (applied at 45 p.s.i. and 300 microns MMD) gave the best yield of the experiment. However, it was not very different from many others in the experiment, nor from Treatments 6, 7, and 8 with the same MMD value. One of these (Treatment 8) was applied with a hollow-cone spray pattern. Doubling the gallonage from 40 to 80 gallons per acre (Treatments 3 and 5, respectively) had little influence on control effectiveness.

In a comparison between Treatments 5 and 14, both of which were applied at 80 gallons per acre, the lower pressure and larger droplet size was slightly less effective than the smaller drops at higher pressure. When 510 micron drops were applied at only 20 p.s.i. and 45 gallons per acre (Treatment 12), the results were equally as good, both in terms of yield and defoliation.

The treatment specifications used for potatoes, as listed in Table 5, were also utilized for an experiment on tomatoes at Wooser in 1956. Manzate, which was used as the fungicide, was applied at the rate of 1.5 pounds per acre. Early blight infection on both foliage and fruit became rather severe by the end of the harvest season. Anthracnose fruit rot was scarce in all sprayed plots and affected only 5.2 percent of the fruits in the untreated check. Late blight was absent. As a result of the attack by early blight, defoliation of the check plots reached 80 percent by the end of the harvest season, and only 1.8 tons per acre of green fruit was left on vines of the untreated plots. The combination of early blight and anthracnose fruit rots caused approximately one-fifth of the fruits in the unsprayed plots to be classed as culls. The data on disease control by the different treatments are given in Table 6.

Changing the spray droplet size from 400 to 100 microns MMD by increasing the pressure, while the gallonage and the size of the nozzle tip were held constant (Treatments 1, 2, 3, and 4) slightly increased the degree of disease control obtained in a comparison of Treatments 1 and 4, without increasing the net yield of good fruit. Doubling the gallonage to 80 gallons per acre with droplet size and pressure held constant (Treatment 5 vs. 3), added nothing to the disease control obtained with 40 gallons.

Changing the nozzle size and/or type with the application rate with the MMD of the spray drops held constant (Treatments 2, 6, 7, and 8) had little effect on the degree of disease control obtained except that in Treatment 2 there was some increase in defoliation above that which occurred in Treatments 6, 7, and 8. This difference is not reflected in yields of green or ripe fruits, or in percent of culls. A change in droplet size, obtained by changing the nozzle size (Treatments 9 and 10), while gallonage and pressure remained constant, showed little difference in disease control. Treatments 12 and 13 were sprays of large MMD applied at a single application rate by varying the nozzle size. There was little difference in disease control between these two treatments. It should be noted that Treatment 11 was applied at the low pressure of 20 p.s.i.

Table 6. Variations in size of the spray droplets and the control of tomato diseases at Wooster, 1956. The fungicide used was Manzate at 1.5 pounds per acre.

Treatment number	Droplet size in mirons MMD	Pressure P.S I.	Application rate G.P.A.	*Nozzle numbers	Net yield tons/acre	Percent of fruits that were culls	Percent of fruits with Anthracnose	Percent of fruits with Early blight	Percent of defoliation on 9/16	Green fruit after last harvest tons/acre
1	400	25	40	9503	17.2	8.5	1.4	6.2	37	4.9
2	300	45	40	9503	17.7	7.7	0.8	6.8	36	4.9
3	200	120	40	9503	16.4	8.5	1.1	6.0	34	6.6
4	100	277	40	9503	16.9	7.0	0.5	5.6	27	6.1
5	200	120	80	9503	16.2	9.6	0.7	7.9	31	5.3
6	300	95	40	9502	18.4	9.1	0.6	6.5	28	6.4
7	300	136	40	9504	17.3	7.9	1.2	4.8	28	6.3
8	300	72	40	D7,C25	17.4	8.0	0.7	6.0	26	5.7
9	400	50	40	9508	15.8	10.7	1.0	7.2	29	5.3
10	280	50	40	9503	16.4	10.2	0.2	8.9	33	5.0
11	502	20	45	9506	18.0	8.0	0.6	5.0	34	4.6
12	510	20	45	9508	17.0	6.9	0.6	5.7	34	5.8
13	488	40	45	9510	17.5	9.0	0.8	7.4	34	5.6
14	488	40	80	9510	16.6	5.2	0.7	3.3	31	7.5
15	No treatment		—	—	12.6	18.8	5.2	16.3	80	1.8
LSD at 5 percent level					1.4					

*Flat spray pattern tips all stainless steel. Hollow cone spray pattern cores hardened stainless steel.

Table 7. **Variations in spray droplet size as they affected insect control and yield on Cobbler potatoes at Wooster, 1956. The insecticide used was a 1 to 1 mixture of DDT and dieldrin applied at 1 pound per acre.**

Treatment number	Droplet size in microns MMD	Pressure P S I.	Application rate G P.A.	*Nozzle Numbers	Yield bu /acre	Potato leafhopper (nymphs per leaf)	Potato flea beetle (holes per leaflet)
1	370	20	40	D5,C25	574	0	2.4
2	219	150	40	D5,C25	645	0	2.3
3	167	250	40	D5,C25	638	0	1.1
4	300	72	40	D7,C25	606	0	1.3
5	132	250	40	D4,C25	578	0	1.4
6	400	33	40	D10.C25	540	0	0.9
7	400	25	40	9503	637	0	2.3
8	300	45	40	9503	599	0	0.9
9	200	120	40	9503	578	0	0.8
10	100	277	40	9503	610	0	0.6
11	510	20	50	9508	599	0	1.0
12	488	40	50	9510	666	0	1.1
13	No treatment	—	—	—	311	8.6	67.8
LSD at 5 percent level					37		

*Flat spray pattern tips all stainless steel. Hollow cone spray pattern cores hardened stainless steel.

In a comparison of application rates in Treatments 13 and 14 an increase from 45 to 80 gallons per acre gave some increase in disease control as shown by decrease in culls from 9.0 to 5.2 percent, most of which was accounted for by a decrease in the percentage of fruits attacked by early blight.

This experiment again demonstrated that mass median diameter as obtained by variations in pressure or nozzle size, played comparatively little part in determining the effectiveness of a specific fungicide formulation in the control of the foliage and fruit diseases of tomato.

The possible effect of variations in spray droplet sizes and gallonage, on the control of leafhoppers and flea beetles on potatoes, was investigated in an experiment conducted at Wooster in 1956. The data relative to this test are given in Table 7. The insecticidal fraction of the spray formulation was a half and half mixture of wettable powders of DDT and dieldrin, which was used at the rate of one pound per acre per application.

In Treatments 1, 2, and 3 the spray droplet size was decreased progressively by increasing the pressure while the disc size in a hollow-cone nozzle assembly, and the gallonage, were held constant. Only the application rate was held constant in Treatments 4, 5, and 6, while the MMD value and the disc size were varied. In Treatments 7, 8, 9, and 10 the droplet size was varied by changing the pressure while the application rate and the size of flat-spray nozzle tips were held constant. Treatments 11 and 12 involved a comparison of sprays with drops of large MMD applied by different size nozzles, at a single application rate.

All treatment variations gave 100 percent control of leafhoppers, as has been the usual experience where potatoes have been sprayed with DDT. There was some variation in the control of flea beetle feeding with changes in spray droplet size, but they were minor. This was true for both hollow-cone and flat-spray patterns.

When the droplet size was decreased by increasing the pressure while the disc size was held constant (Treatments 1 to 3), there was an insignificant decrease in flea beetle damage and an increase in yield. When the disc sizes were changed to give a change in droplet size (Treatments 6, 4, and 5), very slight increase in damage did accompany the decrease in the MMD value. When droplet sizes of 100, 200, 300, and 400 microns MMD were obtained by changing the pressure while the application rate and the nozzle tip size of a flat spray nozzle were held constant (Treatments 10, 9, 8, and 7), there again was a comparatively small decrease in the control of beetle damage with an increase in droplet size as in Treatments 3, 2, and 1. but there was no consistant yield increase. A change in nozzle sizes used in applying sprays of large MMD values (Treatments 11 and 12) without a change in application rate did not affect the control of flea beetle feeding. Thus, again, changes in droplet size, within the ranges existent in this experiment, did not materially affect the degree of insect control with respect to leafhopper infestation and feeding by flea beetles.

In a further study of the effect of variations in spray droplet size, as it was regulated by pressure, rate of application and changes in nozzle aperture, Trithion was applied to eggplant at the rate of 0.38 pounds per acre per application for the control of flea beetles and two-spotted spider mites, *Tetranychus telarius* (L.). Infestation by both pests was very heavy on the unsprayed check plots, and the extent to which they were controlled by the different treatments used in this experiment is indicated in Table 8. That the yield was not greatly affected by the degree of beetle or mite damage is evident from the fact that the yield of the untreated check plots was as great as that of five of the sprayed plots, and statistically significant below that of only one of them. There were only very small differences in the control of flea beetle damage to the foliage and in the number of mites present on the leaves at the time the population counts were made.

In Treatments 1 and 2 the droplet size was changed at the very low application rate of 10 gallons per acre by changing the pressure and the tips in flat-spray nozzles. The droplet size was changed in Treatments 3, 4, and 5 by changing nozzle tips while the pressure and application rate (20 gallons per acre) were held constant, whereas in Treatments 6, 7, 8, and 9 the size of the spray droplets was varied by changing the operating pressure on one size of nozzle. Meanwhile the application rates were held constant. In Treatments 10, 11, and 12, the sizes of the droplets formed by hollow-cone nozzles were varied by changing the pressure while the sizes of the nozzle discs and the rates of applications were held constant. Two sizes of nozzle tips were used in Treatments 13 and 14 to give approximately the same large droplet size (over 500 microns MMD) at the same pressures and rates of application.

Table 8. Influence of variations of spray droplet size, spray pattern and application rate on the control of insects and on the yield of eggplant at Wooster, 1956. Trithion was used as the insecticide at 0.38 pounds per acre per application on a 10-day interval.

Treatment number	Droplet size in microns MMD	P.S.I. Pressure	Application rate G.P.A.	*Nozzle numbers	Yield in pounds per plot	Average number on 100 leaves of: Flea beetle (holes per sq. inch)	Two-spotted mites per sq. inch
1	335	50	10	9502	119	0.1	0.10
2	233	40	10	95015	80	2.7	0.22
3	233	40	20	95015	84	0.5	0.25
4	308	40	20	9503	92	0.8	0.01
5	412	40	20	9504	101	0.1	0.01
6	120	240	35	9503	100	0.6	0.01
7	230	85	35	9503	86	0.2	0.01
8	308	40	35	9503	113	0.1	0.01
9	410	20	35	9503	107	0.1	0.01
10	175	250	35	D5,C25	106	0.1	0.01
11	219	150	35	D5,C25	82	0.1	0.25
12	370	20	35	D5,C25	94	0.1	0.01
13	502	20	35	9506	88	0.1	0.08
14	510	20	35	9508	95	0.2	0.32
15	No treatment	—	—	—	91	85.0	81.00
LSD at 5 percent level					27		

*Flat spray pattern tips all stainless steel. Hollow cone spray pattern cores hardened stainless steel.

The results of this experiment indicate that spray applications may vary widely in drop size and rates of application and still be quite capable of giving good control of such foliage pests as flea beetles and two-spotted mites on the extremely pubescent leaves of eggplant.

1957

In 1957, four experiments that dealt with a study of the relationship between spray droplet size and the control of diseases and/or insects on vegetables were carried out. One was on potato at Wooster in which data on both disease and insect control were obtained. Early planted Irish Cobbler potatoes were sprayed with a formulation of Parzate and a half and half wettable powder mixture of DDT and dieldrin, all applied at one-half the recommended rate of use. Early blight was of no more than medium severity and late blight was absent in the experiment. Leafhoppers and flea beetles caused at least the usual amount of damage on the unsprayed check plots. The data relative to insect control are given in Table 9.

Thirteen spray treatments that involved various combinations of gallonage, size of nozzle aperture, and spray droplet size were compared with an untreated check in this experiment. In Treatments 2, 3, 4, 5, 6, and 7 the droplet size was varied by changing the pressure while the application rate was held constant. Treatments 5 and 6 represent the same droplet size at the transition from one nozzle tip size to another. This change was necessary to obtain a spray having an MMD value as large as 500 microns. Plots 8 and 9, with application rates of 160 gallons per acre applied by two types of spray nozzles were controls, or

Table 9. Spray droplet size and the control of potato diseases and insects on Cobbler potatoes at Wooster, 1957. Parzate at 1.5 pounds per acre and a 1 to 1 mixture of DDT and dieldrin at 1.0 pounds per acre was the spray formulation used.

Treatment number	Droplet size in microns MMD	Pressure P.S.I.	Application rate G.P.A.	*Nozzle numbers	Yield bu./acre	Potato leafhopper (nymphs per leaf)	Potato flea beetle (holes per leaflet)	Percent foliage dead on July 30
1	No treatment	—	—	—	403	14.6	34.8	62
2	115	250	40	9503	668	0	3.0	18
3	200	120	40	9503	653	0	2.1	18
4	300	43	40	9503	643	0	0.9	15
5	400	22	40	9503	633	0	1.8	28
6	400	70	40	9506	701	0	0.6	15
7	500	22	40	9506	690	0	0.5	20
8	115	250	160	9503	609	0	2.5	13
9	275	155	160	D7,C25	637	0	1.9	15
10	132	250	40	D4,C25	779	0	0.5	15
11	200	180	40	D5,C25	704	0	1.8	15
12	300	52	40	D5,C25	646	0	0.8	20
13	300	120	40	D7,C25	667	0	0.7	18
14	400	45	40	D7,C25	666	0	1.1	15
LSD at 5 percent level					47			

*Flat spray pattern tips all stainless steel. Hollow cone spray pattern cores hardened stainless steel.

checks, with which the 40-gallon treatments could be compared. Treatments 10 to 14, inclusive, were applied with nozzles that developed a hollow-cone spray pattern and included drops with an MMD range from 132 to 400 microns. This variation was obtained by varying the pressure with different sizes of nozzle discs.

As usual, where DDT is present, all treatments gave 100 percent control of leafhoppers. There were some differences in the control of flea beetle feeding, but these were slight. The control of early blight on the foliage, as indicated by the degree of defoliation shortly before harvest, varied somewhat with the different treatments. Among the six treatments that were applied in a flat-spray pattern, with an application rate of 40 gallons per acre (numbers 2 to 7, inclusive), only Treatment 5 was appreciably less effective than the others. In that one, which was applied at only 22 p.s.i., early blight control was rather poor and the yield was down slightly. Treatment 2 with its small droplets was no more effective in disease and insect control than were the larger droplets of Treatments 3, 4, 6, and 7. Treatment 8, with its high gallonage and small droplets, gave good control of early blight but was no more effective in checking flea beetle damage than several other of the treatments used, and the yield of potatoes was low. The large spray droplets of Treatment 7 (500 microns MMD) gave good control of flea beetle feeding and fair control of early blight. In the nozzle tip transition from a 9503 tip to 9506 (Treatment 5 vs. 6), the larger tip used with a higher pressure to give a droplet size of 400 microns MMD gave the better control of both flea beetle and early blight damage. There was little to choose between the performances of a flat and a hollow-cone spray pattern in Treatments 8 and 9, both of which involved a high application rate. Treatment 10 applied in a hollow-cone pattern with high pressure and a small droplet size gave the highest yield of the experiment, with good control of flea beetle and early blight damage. In the nozzle disc size transition treatments (numbers 12 and 13) the larger disc with the higher pressure of application gave only slightly better results than the smaller disc and the lower pressure.

In this experiment the data on control of diseases and insects again indicate that rather wide differences in spray droplet sizes provided by changes in pressure or the type of spray nozzle and application rates have little influence on the degree of insect and disease control obtained when spraying potato foliage.

The appearance of the spray droplets of different sizes and the pattern of their distribution on the surface of potato leaves as they appeared in Treatments 2, 3, 4, 5, and 7, are shown in Figure 8. There is a very evident difference in the pattern of spray droplet size and spacing on the leaves between numbers 1 (115 microns MMD) and 5 (500 microns MMD), but numbers 2, 3, and 4 do not appear very different. This will be discussed further later.

The 1957 experimental grouping of treatments on potato was repeated on tomato at Wooster in 1957, by using the same series of droplet size combinations. Late blight became rather severe in the experi-

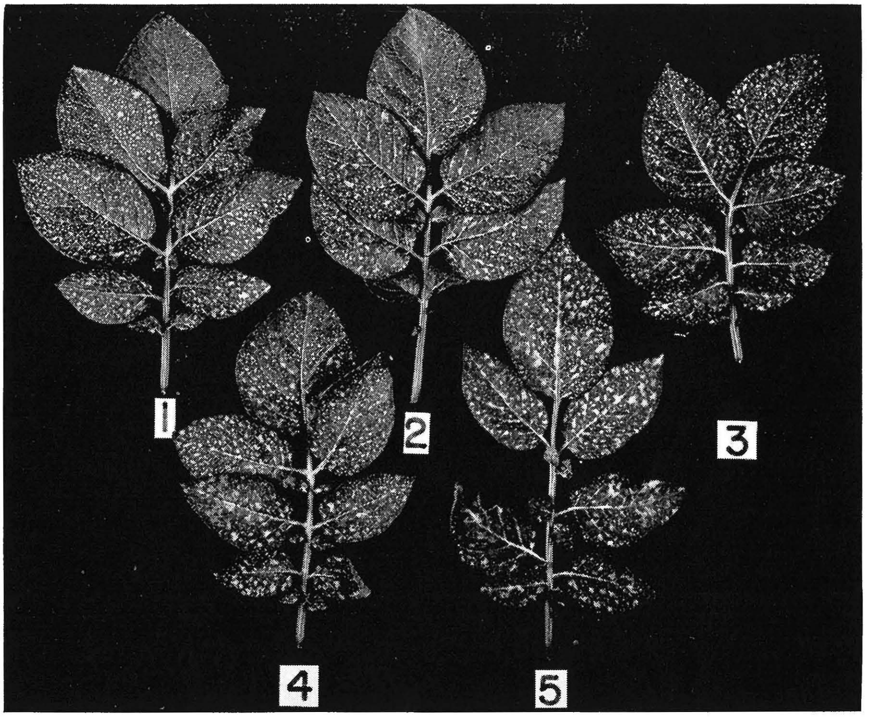

Fig. 8.—Spray patterns formed on potato leaves by different sizes of spray droplets. One equals 115 microns MMD and five equals 500 microns MMD. The other numbers are intermediate in droplet size.

mental area during the latter part of the season, when it destroyed over 20 percent of the fruits picked in the last two harvests. This afforded the first opportunity in this series of experiments to observe the effect of spray droplets of varying MMD applied at low gallonage on the control of late blight. Early blight was rather scarce, both on the foliage and on the fruit. There was comparatively little anthracnose fruit rot, but Rhizoctonia fruit-rot (*Rhizoctonia solani*) was rather plentiful. The data concerning the control of these different diseases are given in Table 10.

As mentioned above the series of treatments used in this tomato experiment was identical with that used on potato as listed in Table 9 and reference should be made to Table 9, and to the discussion on that potato experiment, for a list of their specifications. Since anthracnose fruit rot was scarce, and that caused by Rhizoctonia is difficult to control by any means, most of the discussion will be confined to the control of late-blight fruit rot in this instance.

When four droplet sizes were compared in treatments applied in a flat spray pattern with the same nozzle tip (Numbers 2, 3, 4, and 5), there was little difference in the degree of control of the three fruit rots

Table 10. **Effect of variations in spray droplet size on yield and the control of tomato diseases at Wooster, 1957. The fungicide used was Manzate at 1.5 pounds per acre.**

Treatment number	Droplet size in microns MMD	Pressure P.S.I.	Application rate G.P.A.	*Nozzle numbers	Yield tons/acre	Percent cull fruits	Percent of fruits with Anthracnose	Percent of fruits with Rhizoctonia rot	Percent of fruits with late blight in two harvests
1	No treatment	—	—	—	19.3	18.0	3.4	5.0	21.6
2	115	250	40	9503	19.0	6.4	1.3	4.0	1.0
3	200	120	40	9503	18.8	6.5	1.4	3.8	2.1
4	300	43	40	9503	18.7	6.5	2.0	3.6	1.5
5	400	22	40	9503	18.7	5.9	1.2	3.5	1.6
6	400	70	40	9506	19.1	6.6	1.7	4.1	0.9
7	500	22	40	9506	19.4	5.3	1.6	3.0	0.5
8	115	250	160	9503	19.3	6.0	1.7	3.5	2.1
9	275	155	160	D7,C25	19.2	6.7	2.5	3.0	1.2
10	132	250	40	D4,C25	20.8	7.4	1.5	4.7	2.7
11	200	180	40	D5,C25	18.2	6.6	1.6	3.7	2.1
12	300	52	40	D5,C25	16.8	8.7	2.1	5.7	1.6
13	300	120	40	D7,C25	16.7	6.8	2.5	2.6	1.1
14	400	45	40	D7,C25	19.8	7.7	2.0	3.8	1.3
LSD at 5 percent level					2.6				

*Flat spray pattern tips all stainless steel. Hollow cone spray pattern cores hardened stainless steel.

listed, or in the percentage of total culls. The best control of late blight, accompanied by the lowest percentage of culls, of the experiment was furnished by the largest droplets (500 microns MMD in Treatment 7). There was little difference in the control of fruit rots in Treatments 5 and 6 where spray droplet size was held constant and the transition was made to a larger nozzle size to facilitate the application of a spray of larger droplet size in Treatment 7. The high rates of application by two different nozzle types at rather low MMD's (Treatments 8 and 9) did not add anything to the late-blight control furnished in several of the 40-gallon treatments at the same, or other, spray droplet sizes. Neither was there much to choose between the hollow-cone and flat-spray patterns of these two treatments.

In the hollow-cone pattern series (Treatments 10 to 14, inclusive), all applied at 40 gallons per acre, there was little difference in the disease control furnished by the different droplet sizes. Treatment 14 with a droplet size of 400 microns MMD, did as well as Treatment 10 with much smaller droplets. Neither was there much choice between the average effectiveness in disease control between these hollow-cone spray pattern applications and the flat pressure applications of Treatments 2, 3, 4, 5, 6, and 7.

In summary, the results obtained in this experiment further confirmed the conclusion that sprays of small MMD, applied at high gallonage and pressure, are not necessary for the attainment of good fungicide performance.

As a further test of the effect of varying spray droplet sizes on the degree of insect control obtained, a series of cabbage plots were sprayed at Wooster in 1957 for the control of the imported cabbageworm, *Pieris rapae* (L.), and the cabbage looper, *Trichoplusia ni* (Hubner). The results obtained are given in Table 11.

Treatments 1, 2, 3, and 4 were applied in a hollow-cone spray pattern, all at the same rate per acre. The droplet size was increased by decreasing the pressure and in Treatment 4 it was necessary to increase the nozzle size. Treatments 5, 6, 7, 8, and 9 represent a similar series in which a flat-spray pattern was used. In Treatments 10 and 11, two medium droplet size ranges were applied at a low application rate. Treatment 12 was an untreated check.

In the control of imported cabbage worms there was some indication that large droplets applied at low pressure in a hollow-cone spray pattern might be more effective than were smaller ones applied at higher pressures, when the rate of application was held constant (Treatments 1, 2, 3, and 4). However, when a count was made of cabbage looper populations the droplets of intermediate size showed the lowest counts. There was no appreciable difference in yield among the four treatments at harvest time.

When the spray droplet size was varied by changing the pressure on flat-spray nozzles (Treatments 5 to 9, inclusive), there was again little difference in cabbage worm and cabbage looper populations, with the 500-micron MMD droplets giving as good control as any smaller

Table 11. The effect of variations in spray droplet size on the control of imported cabbage worms and cabbage loopers on cabbage at Wooster, 1957.

Treatment number	Droplet size in microns MMD	Pressure P.S.I.	Application rate G P.A.	*Nozzle numbers	Cabbage worms per plot on July 9	Cabbage worms per 40 plants on Aug. 8	Cabbage loopers per 5 plants Sept. 27	Mean number of heads per plot	Mean yield in pounds per plot
1	175	250	40	D5,C25	3.0	10	10.8	45	345
2	225	132	40	D5,C25	1.7	13	7.8	43	340
3	325	30	40	D5,C25	0.3	6	7.2	43	367
4	425	20	40	D10,C25	0.8	9	11.4	44	368
5	115	250	40	9503	0.3	0	8.0	43	347
6	225	90	40	9503	0.0	9	11.0	43	379
7	325	35	40	9503	0.8	6	7.0	46	334
8	425	40	40	9508	0.5	7	9.2	42	348
9	500	23	40	9508	0.0	5	9.6	44	431
10	200	153	20	9501	0.3	9	8.8	44	347
11	300	37	20	95015	0.3	4	8.8	43	358
12	No treatment	—	—	—	17.0	44	32.0	42	296

Note: One nozzle per plant row was used in applying Treatments 1 to 8, inclusive, whereas two nozzles per row were used for Treatments 10 and 11.

*Flat spray pattern tips all stainless steel. Hollow cone spray pattern cores hardened stainless steel.

size. Again, there were no significant yield differences in the differently sprayed plots. When the application rate was halved to 20 gallons per acre in Treatments 10 and 11, there was again no difference in the degree of cabbage worm and cabbage looper control obtained with applications of spray droplet sizes of 200 and 300 microns MMD.

In this experiment it was demonstrated that large spray droplets formed at low pressure will give equally as good control of the cabbage worm and the cabbage looper as will smaller droplets formed at higher pressures, and that application rates as low as 20 gallons per acre are still capable of giving a satisfactory degree of control.

1958

One of the most fruitful experiments of this spray droplet size series was one performed on tomatoes in 1958, at Wooster. In this instance disease incidence was high and the control furnished by spraying with Manzate at 1.5 pounds per acre per application varied more with some treatments than usually happened in these experiments. One treatment was included in which the fungicide was used at the usual rate of 3 pounds per acre and it gave considerably better control of all of the diseases in the tomato complex than did the weaker dosage, even when the latter was applied at 160 gallons per acre. Early blight was of medium severity, both on foliage and fruit. Late blight came into the plots in September and caused a considerable loss of fruit and of foliage by the end of the month. Anthracnose caused a loss of 10 percent of the fruits in the untreated check plots, which was somewhat higher than usual. The data relative to the spray specifications and the degree of disease control obtained are given in Table 12.

Treatment 1 was an untreated check. Numbers 2, 3, 4, and 5 were applied at a low application rate (20 gallons per acre) with whatever flat spray nozzle tips were required to give the desired application rate. The desired MMD's were then obtained by choosing a suitable operating pressure for each nozzle used. The same procedure was followed in applying Treatments 7, 8, 9, 10, and 11, but the application rate was doubled to 40 gallons per acre. Treatment 6 was included as a treated check in which the dosage of the fungicide being used was doubled to equal the usual rate of use (3.0 pounds per acre instead of the 1.5 pound rate being used in all of the other treatments included in the experiment). Treatments 12, 13, 14, 15, and 16 were applied in the same manner and with about the same spray droplet size ranges as the other two series just mentioned, except that a hollow cone spray pattern was substituted. Treatment 16, with its large droplet size, was applied with only one nozzle per 66-inch tomato row, whereas two nozzles were used with all other treatments. In Treatment 17, the application rate was increased to 160 gallons as a control check.

In the 20-gallon series (Treatments 2 to 5) there was little difference in the disease control furnished by the sprays of different droplet sizes. In the 40-gallon flat-spray series (Treatments 7 to 11), the smallest droplets (115 microns MMD) gave the best disease control in all

Table 12. **Influence of spray droplet size on disease control and yield on tomatoes at Wooster, 1958. Manzate used as the fungicide at 1.5 pounds per acre per application[1].**

Treatment number	Droplet size in microns MMD	Pressure P.S.I.	Application rate G.P.A.	*Nozzle[2] numbers	Net yield tons/acre	Percent cull fruits	Percent of fruits with Anthracnose	Percent of fruits with Early blight	Percent of fruits with Late blight	Percent defoliation
1	No treatment	—	—	—	11.4	20.9	10.0	6.3	10.6	72
2	200	160	20	95015	13.3	9.4	3.0	3.2	2.8	39
3	300	43	20	9503	14.8	7.1	2.0	1.2	3.6	32
4	400	38	20	9504	15.6	6.9	2.5	1.5	2.3	32
5	500	25	20	9506	13.6	7.3	3.4	2.0	3.0	41
6	300	128	40	9504	15.7	2.7	1.3	0.3	0.6	30
7	115	250	40	9503	15.3	4.8	1.8	1.1	1.9	31
8	200	120	40	9503	14.8	9.2	4.0	2.3	2.8	35
9	300	128	40	9504	13.4	9.2	2.4	2.1	2.3	34
10	400	38	40	9504	13.5	11.7	4.0	2.9	3.1	40
11	500	25	40	9506	15.0	10.0	2.2	1.8	2.9	34
12	132	250	40	D4,C25	14.8	7.5	3.9	2.7	2.3	34
13	200	240	40	D5,C25	14.7	7.0	1.9	1.5	3.7	36
14	300	72	40	D5,C25	14.1	7.5	2.7	1.4	2.5	31
15	400	15	40	D5,C25	15.0	10.4	3.0	1.5	3.4	35
16	500	30	40	D6,C25	13.2	8.0	3.1	2.3	2.1	35
17	365	97	160	9506	14.7	10.7	2.5	2.0	4.9	34
LSD at 5 percent level					1.3					

*Flat spray pattern tips all stainless steel. Hollow cone spray pattern cores hardened stainless steel.

[1]Treatment 6 was applied at 3 pounds per acre

[2]All plots sprayed with 2 nozzles per row except Treatment 16 where only one was used

categories and the highest yield of good fruit. However, droplets of 500 microns MMD did as well or better than those of 200, 300, or 400 microns. In Treatment 6 in the 40-gallon series, in which twice as much fungicide was applied as in the others, the disease control was the best of the experiment and the net yield of good fruit was the highest.

In the hollow-cone spray pattern series (Treatments 12 to 16) the smallest droplets applied at the highest pressure gave no better disease control than did several of the larger sizes applied at lower pressures. The yield of disease-free fruit was lowest of the series with the largest droplets. When the rate of application was quadrupled to 160 gallons per acre (the standard or check rate used in most of these droplet size experiments), the disease control was no better in any category than was obtained with several of the treatments applied in higher concentrations of the fungicide spray formulations applied at 40 and 20 gallons per acre.

The data averages of Table 12A were prepared to aid in a discussion of comparative performance of flat and hollow-cone nozzle patterns, and of different droplet sizes. In a comparison of flat and hollow-cone spray patterns, all applied at 40 gallons per acre, there was essentially no difference in performance so far as the control of foliage and fruit diseases was concerned. When the data for the different droplet sizes were averaged it was apparent that Treatments 7 and 12 with the smallest droplets gave slightly better results in terms of disease control and yield than did the larger sizes. However, that the differences in performance were not great is shown by the fact that the 300-micron droplets gave better control of anthracnose and early blight fruit rots and showed slightly less defoliation than was present in the average data for Treatments 7 and 12.

Thus, in this experiment, with a higher than average incidence of disease, there was still very little difference in the degree of control obtained with applications made with 20, 40, and 160 gallons of water per acre, with flat and hollow-cone spray patterns, and with spray applications that ranged in drop size from 115 to 500 microns MMD. Pressures used to obtain these spray droplet sizes ranged from a low of 15 to as high as 250 pounds per square inch. It should, from the grower's viewpoint be remembered that the use of 3.0 instead of 1.5 pounds of maneb definitely increased the degree of disease control obtained.

1959

In 1959, another droplet size experiment was arranged on tomatoes being grown at Wooster. In this instance early blight became severe on both foliage and fruit before the end of September. Late blight was absent and anthracnose was less common than usual. The almost epidemic severity of early blight made that disease very difficult to control and the use of Manzate at only 1.5 pounds per acre per application resulted in a high percentage of fruit rot and a greater than usual percentage of foliage loss in the sprayed plots. This resulted in a wider spread between the more and the less effective treatments in terms of disease control. The results obtained are indicated in Table 13.

Table 12A. **Comparative average degrees of disease control on tomatoes by flat and hollow cone spray patterns, and by different sizes of spray droplets.**

Averages of	Treatment numbers see Table 12	Average net yield tons/acre	Average percentages of Culls	Anthracnose	Early blight	Late blight	Defoliation
Nozzle patterns							
Flat	7 to 11	14.4	9.0	2.7	2.0	2.9	36
Hollow-cone	12 to16	14.2	8.1	3.2	2.3	2.8	36
Droplet sizes MMD in microns							
100	7 & 12	15.0	6.2	2.9	1.9	2.1	33
200	8 & 13	14.7	8.1	2.9	1.9	3.2	35
300	9 & 14	13.7	5.8	2.5	1.7	2.4	32
400	10 & 15	14.2	11.0	3.5	2.2	3.2	37
500	11 & 16	14.1	9.0	2.6	2.0	2.2	34
Sprayed check	17	14.7	10.7	2.5	2.0	4.9	34
Unsprayed check	1	11.4	20.9	10.0	6.3	10.6	72

Table 13. Relationship between spray droplet size and disease control and yield on tomatoes at Wooster, 1959. Manzate at 1.5 pounds per acre per application was the fungicide used.

Treatment number	Droplet size in microns MMD	Pressure P.S.I.	Application rate G P A	*Nozzle numbers	Net yield tons/acre	Percent cull fruits	Percents of fruits with Anthracnose	Percent of fruits with Early blight	Percent defoliation
1	365	97	160	9506	18.2	10.9	1.8	13.2	59
2	115	250	40	9503	17.1	9.0	1.3	10.1	52
3	200	120	40	9503	17.9	10.4	1.0	12.7	55
4	300	128	40	9504	18.0	9.4	1.8	9.7	58
5	400	38	40	9504	16.4	10.8	1.7	12.2	65
6	500	25	40	9506	18.0	9.6	2.6	11.0	46
7	200	120	15	9503	17.3	9.7	1.2	10.1	61
8	300	42	15	9503	15.3	10.3	1.5	11.9	66
9	400	22	15	9503	16.9	12.8	1.5	13.5	65
10	400	38	15	9504	19.5	10.3	1.3	12.5	62
11	500	25	15	9506	18.1	9.9	1.4	10.2	54
12	132	250	40	D4,C25	19.4	9.1	1.0	10.8	46
13	200	240	40	DTC4,C25	18.3	9.0	1.4	10.1	47
14	300	70	40	DTC4,C25	15.6	10.7	1.9	10.5	59
15	400	15	40	DTC4,C25	16.8	12.2	2.4	11.4	67
16	No treatment	—	—	—	14.8	15.9	3.0	18.5	80
LSD at 5 percent level					2.7				

*Flat spray pattern tips all stainless steel. Hollow cone spray pattern TC discs were tungsten carbide, all cores were hardened stainless steel.

Treatment 1 was applied at 160 gallons per acre and provided a sprayed check with which the lesser rates of water used in the experiment could be compared. In Treatments 2, 3, 4, 5, and 6 flat-spray nozzles were used to apply 40 gallons per acre, and the droplet size was varied by altering the pressure used with different nozzle tips. The same procedures were used in Treatments 7, 8, 9, 10, and 11, except that only one nozzle per row was used and the application rate was lowered to 15 gallons per acre. In Treatments 9 and 10 the same droplet size was applied by using nozzle tips of two different sizes with a slight increase in pressure on the larger tip and an increase in tractor speed to maintain an application rate of 15 gallons. In treatments 12, 13, 14 and 15 an application rate of 40 gallons per acre with a hollow-cone pattern was used, and variations in droplet size were obtained by changing the pressure. Treatment 16 was an untreated check.

Treatments 2 to 6, inclusive, ranged in spray droplet size from 115 to 500 microns MMD, and pressures from 250 down to 25 pounds per square inch were used. There was comparatively little difference in disease control or in net yield within this series, with the largest drops doing approximately as well as the smallest. The smaller droplets gave the best control of anthracnose fruit rot, and the largest gave the best control of early blight on the foliage. When the application rate was only 15 gallons per acre, applied with one nozzle per row (Treatments 7 to 11, inclusive), droplets of 500 microns MMD (Treatment 11) again did as well in most categories of disease control as did any of the smaller sizes, also they gave the best control of early blight on the foliage. When sprays of 400 microns MMD were applied by two sizes of flat-spray nozzles (Treatments 9 and 10), the larger sized nozzle gave slightly the better results in all categories of comparison. In the series of treatments applied in a hollow-cone pattern (numbers 12 to 15, inclusive), the smallest droplets (132 microns), applied at a pressure of 250 pounds, gave results equal to the best of the group of four treatments, and the largest droplets (400 microns) gave the poorest disease control in all ratings. The use of 160 gallons of water per acre to apply the same quantity of fungicide as was used at lower rates of application gave no better disease control on the fruit or foliage than the majority of the treatments applied with as little as 15 or 40 gallons of spray.

The data of Table 13A are presented to again provide comparisons of average performance in terms of disease control of two rates of application, two types of spray patterns, and five different sizes of spray droplets. An application rate of 15 gallons per acre gave slightly poorer results in four of the five disease ratings used, and gave about equal control of anthracnose fruit rot compared to the higher gallonage. In a comparison of flat and hollow-cone spray patterns, the latter gave the better control of early blight on the fruit and on the foliage, whereas the flat pattern gave about as good control of anthracnose fruit rot and a slightly lower percentage of cull fruits. The net yields were essentially the same. The situation with regard to the comparative performance of different droplet sizes is not definitive, since the smaller

Table 13A. Comparative effectiveness of 15 and 40 gallon per acre applications of spray material, of flat and hollow cone spray patterns and of various sizes of spray droplets in the control of tomato diseases.

Averages of	Treatment numbers see Table 13	Net yield tons/acre	Percent cull fruits	Percent fruits with Anthracnose	Percent Early blight	Percent defoliation
Application rate						
15 g.p.a.	7 to 11	17.4	10.6	1.4	11.6	62
40 g.p.a.	2 to 6	17.5	9.8	1.7	11.1	55
Nozzle patterns						
Flat	2 to 5	17.4	9.7	1.5	11.2	58
Hollow-cone	12 to 15	17.5	10.3	1.7	10.7	55
Droplet size, MMD						
100 + Microns	2 & 12	18.2	9.0	1.1	10.4	49
200 + Microns	3 & 13	18.1	9.7	1.2	11.4	51
300 + Microns	4 & 14	16.8	10.0	1.8	10.1	58
400 + Microns	5 &15	16.6	11.5	2.0	11.8	66
500 + Microns	6 & 11	18.0	9.6	2.6	11.0	46
Sprayed check	1	18.2	10.9	1.8	13.2	59
Unsprayed check	16	14.8	15.9	3.0	18.5	80

drops gave slightly better control of anthracnose and early blight on the fruit, whereas the larger drops were slightly better in controlling disease on the foliage. The percentage of cull fruits was approximately equal for small versus large spray droplets.

Thus, in a year when a disease (early blight) reached near epidemic proportions a half-the-recommended strength of a fungicide (Manzate) applied to tomatoes again failed to give good control of the disease. This should furnish the maximum opportunity to distinguish between treatments on the basis of their comparative effectiveness in the control of the disease. However, even under these conditions, there was little to choose between large spray droplets applied at low pressures and much smaller ones applied at higher pressures. Neither did a treatment applied at 160 gallons per acre give any better disease control than several others applied at 15 and at 40 gallons.

1960

The experimental work on the effect of varying the size of spray droplets on disease control was continued in 1960. The fungicide (Manzate) was again applied at half the usually recommended rate (1.5 pounds per acre) on a 10-day schedule to tomatoes being grown at Wooster. The usual experimental procedure was varied by setting the transplants at 2500 (the usual number) and at 5000 per acre in an effort to determine whether disease control would be more difficult with higher than usual plant populations. None of the fruit diseases were of more than average severity, but defoliation by early blight was almost 100 percent by the end of September in the unsprayed check plots. The quantity of green fruit left on the plants at the end of the season is a good indicator of the degree of disease control which has been maintained during the latter half of the growth period, and this varied rather widely for some of the treatments used, being very low on the unsprayed plants. The net yield of good fruit was very high in this experiment and varied but little between planting rates of 2500 and 5000 plants per acre. The data obtained on disease control and yield are given in Table 14 where they represent averages of eight plot replicates, four at each planting rate.

Treatments 1 to 5, inclusive, represent a series in which the droplet size was varied by using different flat-spray nozzle tips and varying the operating pressures. All were applied at 35 gallons per acre. Treatments 6, 7, 8, and 9 made up a similar series, except that hollow-cone nozzles were used. In Treatments 10 to 14, inclusive, the droplet size was held constant while the application rate was varied by changing the pressure in combination with changes in the disc size of hollow-cone nozzles. Treatment 15 provided an unsprayed check.

In Treatments 1 to 5, in which the spray was applied in a flat pattern in droplets that varied from 115 to 450 microns, the percentage of cull fruits was identical for the largest and smallest drops. The smallest droplets gave slightly better control of anthracnose and of defoliation. Some of those of intermediate size gave even better control of early blight on the foliage and fruit and a lower percentage of culls than did

Table 14. The effect of spray droplet size on the control of tomato diseases and yield at Wooster, 1960. Manzate at 1.5 pounds per acre was the fungicide used.

Treatment number	Droplet size in microns MMD	Pressure P.S.I.	Application rate G.P.A.	*Nozzle numbers	Net yield tons/acre	Percent cull fruits	Percent showing Anthracnose fruit rot	Percent infested with Rhizoctonia	Percent of fruit with Early blight lesions	Percent defolitaion on Sept. 30	Percent of fruit green at end of season
1	450	40	35	9506	40.9	2.65	1.33	0.87	0.18	38	7.0
2	350	76	35	9504	49.9	2.74	1.11	1.26	0.24	37	5.2
3	250	167	35	9502	40.7	1.85	0.98	0.58	0.28	34	7.6
4	150	192	35	9503	41.2	1.86	0.95	0.65	0.17	31	6.7
5	115	250	35	9503	41.3	2.65	1.00	1.26	0.19	33	7.6
6	450	76	35	D7,C25	40.4	2.35	1.07	1.05	0.30	34	7.1
7	350	24	35	D5,C25	41.5	2.57	1.15	1.06	0.37	43	5.4
8	250	65	35	D4,C25	38.9	3.14	1.24	1.50	0.35	38	6.1
9	132	250	35	D4,C25	41.6	2.35	1.20	0.98	0.24	28	7.9
10	250	65	20	D4,C25	42.8	2.11	1.47	0.48	0.29	41	5.3
11	250	98	40	D5,C25	41.2	1.83	0.95	0.54	0.30	38	6.3
12	250	98	60	D5,C25	41.2	2.52	1.10	0.98	0.51	42	4.7
13	250	98	80	D5,C25	41.6	2.49	1.18	0.81	0.50	45	5.0
14	250	195	160	D7,C25	41.9	3.03	1.35	1.22	0.35	40	4.8
15	No treatment	—	—	—	38.5	9.12	6.73	1.79	1.07	96	0.9
Averages for											
Flat-spray patterns (Treatments 1-5)					41.0	2.35	1.07	0.92	0.21	35	6.8
Hollow-cone patterns (Treatments 6-9)					40.6	2.60	1.16	1.15	0.32	36	6.6

*Flat spray pattern tips all stainless steel. Hollow cone spray pattern cores hardened stainless steel.

either the large or the small spray droplets in the series. When the drop size was varied between 132 and 450 microns in a hollow-cone pattern (Treatments 6, 7, 8, and 9), the control performance was best at the two extremes in droplet size. The control of defoliation was the best of the experiment with droplets of 132 microns (Treatment 9), and the degree of control was accompanied by the largest yield of green fruit. When the application rate was varied from 20 to 160 gallons per acre, while the droplet size was held constant at 250 microns, the 20-gallon rate gave a lower percentage of cull fruits and better control of early blight on the fruit and foliage than did the treatment made at 160 gallons. In a comparison of the average performance of flat and hollow-cone spray patterns (last two lines of Table 15) the flat pattern did slightly better in all categories of disease control than did the hollow-cone application.

1961

In 1961, still another experiment that dealt with the relationship between spray droplet size and disease control on row crops was performed, but this time on sugar beets for the control of Cercospora leaf spot (*Cercospora beticola*). The use of a fixed copper (Tribasic) applied at 6 pounds per acre on a 10-day schedule with a fixed-boom hydraulic sprayer provided data not only on disease control, but made it possible to study the influence of variations in application techniques on the extent to which the fungicide adhered to the foliage. Cercospora leaf spot became severe in the unsprayed check plots of this experiment, and this afforded an excellent opportunity to observe any worthwhile differences in disease control by the differently applied treatments. The data obtained on disease control and on the adhesion of the fungicide used are presented in Table 15.

Treatment 1 was an unsprayed check. In Treatments 2 to 6, inclusive, all of which were applied at 40 gallons per acre, the droplet size was varied from 100 to 500 microns by varying the pressure used with flat-spray nozzle tips of different sizes. Treatments 7 to 11, inclusive, represented a similar series applied at the same gallonage and over approximately the same range of droplet sizes, but with a hollow-cone spray pattern. Treatment 12 was included as a control, or check, sprayed with 160 gallons of water per acre at a pressure of 300 p.s.i., with which all other treatments used could be compared.

On September 24, a detailed count was made of the number of diseased leaves on the plants in 20 feet of row in each of the four replicates of each treatment, and from this an average of the percentage of leaves diseased was calculated. On October 17, a careful estimate of the percentage of foliage dead in each plot was also made. Both sets of data are given in Table 15. On the basis of the data collected on September 24, the 100-micron MMD spray formed at a pressure of 272 p.s.i. (Treatment 2), gave somewhat better conrol of leaf spot than did those of 500 microns MMD, formed at only 31 p.s.i. (Treatment 6). However, on

Table 15. Spray droplet size and the control of Cercospora leaf spot on sugar beets at Fremont in 1961, and the relationship existing between droplet size and the adhesion of Tribasic applied at 6 pounds per acre per application.

Treatment number	Droplet size in microns MMD	Pressure P.S.I.	Application rate G.P.A.	*Nozzle numbers	Percent leaves diseased on Sept. 24	Percent disease control	Percent foliage dead on Oct. 17	Yield of beets tons/acre	Pounds of sugar produced per acre	Copper deposit in terms of $\mu g/cm^2$ Initial	Copper deposit in terms of $\mu g/cm^2$ Weathered	Percent Adhesion
1	No treatment		—	—	66.3	—	69	16.9	4732	—	---	—
2	100	272	40	9503	8.6	89.2	15	20.8	5949	23.0	6.64	28.9
3	200	116	40	9503	8.2	89.7	20	—	—	27.2	7.92	28.4
4	300	49	40	9503	8.9	88.9	19	—	—	25.0	7.35	28.7
5	400	82	40	9506	9.5	88.1	17	—	—	24.7	8.01	32.4
6	500	31	40	9506	10.5	86.9	16	19.5	5577	27.0	7.28	27.0
7	125	275	40	D4,C25	5.8	92.7	16	19.8	5663	34.9	9.00	25.9
8	200	112	40	D4,C25	9.2	88.5	20	—	—	30.0	10.07	33.6
9	300	35	40	D4,C25	11.0	86.2	21	—	—	40.6	9.72	23.9
10	400	43	40	D7,C25	11.3	85.9	19	—	—	28.9	6.38	22.1
11	475	20	40	D7,C25	9.4	88.2	15	20.3	6008	39.9	9.77	24.8
12	300	300	160	D7,C25	8.8	89.0	15	19.5	5733	20.4	6.57	30.0
Average by												
Flat-spray patterns					9.1	88.6	17.4	—	—	25.4	7.44	29.1
Hollow-cone patterns					9.3	88.3	18.2	—	—	34.9	8.99	26.1

*Flat spray pattern tips all stainless steel. Hollow cone spray pattern cores hardened stainless steel.

October 17 (about 5 weeks after the last spray application was made) there was little to choose between the two treatments so far as disease control was concerned. The smaller droplets did give a slightly higher yield of beets and of sugar in pounds per acre, indicating that disease control throughout the season had been better than with the 500-micron size of droplet. In the series applied in a hollow-cone pattern (Treatments 7 to 11), the disease control on September 24 was definitely the best of the group in the plots sprayed with the smallest drops at the highest pressure (Treatment 7), but by October 17 this earlier superiority had disappeared and Treatment 11, with the largest drops applied at a pressure of only 20 p.s.i., showed no more dead foliage than did Treatment 7. In this instance the larger drops were accompanied by a higher yield of beets and more pounds of sugar per acre. The high gallonage-high pressure application of Treatment 12 failed to give any better disease control than did some of the treatments applied at lower gallonages and pressures. In averages of the disease control furnished by the five different treatments applied by both flat and hollow-cone spray patterns (last two lines of Table 15), it appears that the flat pattern gave slightly the better results, and that the average of all ten treatments applied at 40 gallons per acre was not appreciably different from that of Treatment 12 applied at four times the gallonage and at a higher pressure than any of the ten applied at the lower gallonage.

In this experiment on sugar beets it was possible to obtain data on the initial and weathered deposits of copper on the leaves, and from these data to calculate the percentage of adhesion after 10 days of weathering. This was done by taking leaf samples from the differently treated plots just after they were sprayed and again 10 days later just before they were to be sprayed again. The data presented here are the averages for five different applications and are presented in Table 15 in terms of micrograms of copper per square centimeter of one side of the leaf surface. Data on the percentages of adhesion are also presented.

The data on initial copper deposits for the five treatments applied in a flat-spray pattern (Numbers 2 to 6, inclusive) indicate very little difference with the different droplet sizes used. This was also true for the weathered deposits, but the smallest drops did give both the smallest initial and weathered values. The percentages of adhesion were also very similar with all five treatments. There was more variation in the size of the initial deposits when the treatments were applied with a hollow-cone nozzle (Numbers 7 to 11, inclusive), but there is no apparent reason why the difference between Treatments 9 and 10 should have been so great, either in the size of initial or the weathered deposits. However, all data were of similar magnitude for the smallest (Treatment 7) and largest (Treatment 11) droplets. Both the initial and weathered deposits for Treatment 12, which was applied with 160 gallons of water per acre, were lower than for those applied in flat or hollow-cone patterns in the droplet-size series.

In averages of the initial and weathered deposits for the five treatments applied with each type of spray pattern (last two lines of Table 15), the initial deposit was about the same for either pattern and there was comparatively little difference in the weathered deposits. Better adhesion of the spray deposit for the flat pattern shows up in the average percentages of adhesion in the last column of the table, where the flat pattern showed an average adhesion of 29 percent compared with 26 percent for the hollow-cone application.

Thus, in summary, the data of this experiment indicate that variation in droplet size of the spray application, as brought about by various combinations of pressure, rate of application, and the use of nozzle tips or discs of different sizes, have comparatively little effect on the degree of disease control obtained on sugar beets, as has also been true in previous years on other crops. Neither did droplet size have any marked influence in determining the size of the initial and weathered deposits of the copper fraction of the fungicide used for disease control, nor on the degree to which it adhered to the beet foliage.

Discussion

A search of the literature relative to the significance of droplet size as it may influence the effectiveness of pesticide spray applications in the control of diseases, insects, weeds, etc., reveals that comparatively little is accurately known of the role that this factor may play in pest control. Of the published data now available, a considerable portion deals with the manner in which variations in spray-droplet size may influence the effectiveness of herbicides in weed control. A number of papers contain discussions of the influence of droplet size on insect control, and a few others attempt to evaluate the role that the size of spray droplets may play in determining the effectiveness of fungicide applications in the control of foliar plant diseases.

Behrens (1) considered the spacing of drops to be more important than their size in determining the effectiveness of 2,4,5-T as an herbicide, and estimated that there should be approximately 72 drops per square inch of leaf surface to obtain the optimum plant response. Smith (9) reported that 2,4-D in drops of 250 to 561 microns in diameter were more injurious to beans than other drops with an average diameter of 30 microns. In contrast to this Ennis and Williamson (3) found that drops with diameter of 0.1 mm (100 microns) were more effective, in low-volume applications, in decreasing soybean yields (because of plant injury) than were others in the range 0.3 mm (300 microns). They ascribed this effect to a greater absorption and subsequent translocation of the toxic substance from the small, closely spaced drops. than from larger drops spaced more widely apart. Mullison (5) has taken the opposite view and credits one large drop with being as lethal to a bean plant as many smaller ones formed from the same volume of material, and because of this he considers that the quantity of 2,4-D applied to a plant is the determining factor in herbicidal effectiveness rather than the number and size of the drops into which that quantity, or volume, is divided during application.

However, it is questionable whether the factors that may regulate the effectiveness of herbicidal compounds are functional in determining the comparative performance of large or small drops in the control of insects and diseases, since insects move about over the surface of treated leaves and thus encounter the toxic agent; while, on the other hand. components of a fungitoxic material must be closely spaced over the surface of the treated leaf during weather periods suitable for spore germination, if infection by the causal fungus is to be prevented.

Wilkes (11) found that droplets of an insecticidal spray material were more effective in the control of certain cotton insects when their diameters ranged between 50 and 150 microns than if the drops were still larger. In contrast to this Yeomans (19) and Yeomans and Rogers (20) called attention to the fact that the size of the spray droplet plays an important role in regulating the extent to which spray materials are transported from the point of release to the surface of the foliage being treated, and since the momentum of small drops may not be sufficient to carry them from their point of origin to the point of deposition, an unnecessarily large portion of spray volume may be dissipated because of drift and failure of the droplets to make foliar contact.

This failure of small droplets to be deposited on the foliage being treated could also become functional in determining the effectiveness of fungicidal sprays in the control of foliar diseases, particularly in the use of air-blast equipment if a high percentage of the spray volume is in very small drops. Ogawa and Yates (6) found that large, medium and small drops were equally effective in the control of three different almond diseases, and also that the degree of control was similar when applications of 0.85, 1.60 and 3.85 gallons per tree were made with an air-carrier sprayer. In this connection, unpublished data obtained by the authors have shown that air-blast applications as low as 20 gallons per acre can be equally as effective in the control of foliar diseases of sugar beet and tomato as others made at much higher gallonages.

Since continuity of the foliage deposit pattern and close spacing of the particles of the fungicidal ingredient are considered essential to good disease control, it must be assumed these conditions are established during a successful spray application or soon thereafter. If the spray coverage were uniform and resulted from drops of large size, it might be expected they would be widely scattered. The distribution of sizes within the spray from the nozzles used in these experiments has been found to be far from uniform in size as reported by Hedden (4). It was pointed out in Table 1A that, for a typical flat spray nozzle used in making the applications discussed herein, most of the drops are in small sizes. One can theorize that a gallon of spray broken into drops 200 microns in diameter would provide an application of 5,964 x 10^5 cubic microns of spray material per square inch if uniformly distributed over an acre. This would place the material in 142 drops per square inch (about 1 drop per 4½ sq.mm.). However, this volume broken up into a 200 micron MMD spray by the nozzle making the deposit measured at 250 p.s.i. in Table 1A would deposit about 12,546 drops per square inch (about 87 drops per 4½ sq. mm.) distributed in size ranges about as follows:

0 - 20	microns,	11,928 drops
21 - 100	"	490 drops
101 - 200	"	101 drops
201 - 300	"	21 drops
Over 300	"	6 drops

This means that about half the volume would be contained in the 12,519 drops in the first three size classifications, ranging from 0 to 200 microns in diameter, or over eight times the number of drops distributed in the theoretically uniform spray. Similar comparisons could be made for even larger MMD sprays.

A non-uniform spray such as this should also cover the surface more thoroughly since the small droplets would fill void spaces between larger drops and thus may give a more nearly complete coverage than would be obtained by randomly placed drops of uniform diameter, unless the latter were all in the small size range.

Initial velocity of the fluid leaving the orifice of the nozzle yielding the data shown in Table 1A is about 1.7 miles per minute (over 150 feet per second) when operated at 250 p.s.i. The spray samples were collected at 10 to 14 inches from the orifice depending upon the location in the spreading spray pattern. Many pesticide applications made by hydraulic sprayers are applied from nozzles located rather close to the crop foliage. Deposits similar to those described above could be expected under conditions in which the drops still retained much of the energy imparted to them by their initial velocity.

When low-volume large MMD (400 to 500 microns) sprays are applied by nozzles of this type, there are large numbers of small drops present (see percentage of various size classifications Table 1A). This low volume of material distributed over the leaf area as a dried residue may not provide a continuous barrier of protection. However, when solubilized or suspended by dew or rainwater and then spread about (redistributed), this dispersion into drops of many intermingled sizes contributes to a ready joining of the wetted areas into a film equally as continuous as that which might have resulted from the application of a spray pattern having an MMD of only 100 microns. In many of the experiments reported here, sprays of 400 to 500 microns MMD gave a degree of pest control which was equal to that provided by sprays of 100 to 135 microns MMD formed at different pressures but applied at the same treatment rate. This indicated there were sufficient numbers of drops, even in the sprays of large MMD to provide the necessary protective cover for pest control; or, that redistribution as described above readily takes place in such deposits to provide the required foliage or fruit protection.

Summary

A revolutionary change in the techniques of row-crop spraying in the late 1940's and early 1950's resulted in a reduction in the quantity of water used to spray a unit area, accompanied by a corresponding increase in the concentration of the active ingredient in the spray formulation to maintain the same rate of pesticide use per unit area. This reduction in the application rate and the use of more concentrated spray mixtures was necessarily accompanied by a change in the size of nozzle (disc or tip) apertures and/or a reduction in pump pressures to provide the desired reduction in spray volume. With these changes in volume and pressure, the part that the size of spray droplets might play in the degree of disease or insect control obtained became more important than formerly. The larger droplets formed by a given nozzle under the influence of lower pressures and delivery rates could conceivably result in the failure to establish a sufficiently continuous film or pattern of spray droplets on the surface of the foliage being treated to assure insect, and more particularly, disease control.

In an effort to determine the comparative effectiveness of spray droplets of different sizes in the control of diseases and insects on row crops, a cooperative experimental program between the Departments of Botany and Plant Pathology, and Zoology and Entomology of the Agricultural Experiment Station, and the Agricultural Engineering Research Division, A.R.S., of the U.S. Department of Agriculture, located at Wooster, Ohio, was initiated in 1952. This has since been continued to the present time through a series of more than 20 different experiments.

In these experiments variations in pump pressures and the size of the nozzle aperture were utilized to provide a range in spray droplet size from 100 to 500 microns mass median diameter. Row crops such as tomato, potato, eggplant, cabbage, and sugar beet were sprayed for the control of various disease and insect pests with different fungicides and insecticides. The application of the spray formulations under carefully controlled conditions has been carried out by the engineering personnel of the U.S. Department of Agriculture, and the collection of the data on disease and insect control was supervised by various members of the departments of Botany and Plant Pathology and Zoology and Entomology of the Ohio Agricultural Experiment Station.

In a series of four experiments that involved the control of the early (Alternaria) and late (Phytophthora) blights of potato, it was found that variations in spray droplet size had comparatively little influence on the degree of disease control obtained. Droplets of 500 microns MMD gave slightly less control than others of 100 microns (formed at much higher pressures than the larger drops) in some instances, but the differences were minor.

In a similar series of five experiments designed to observe any possible relationship between spray droplet size and the control of the potato leafhopper and of the degree of feeding by the potato flea beetle, it was evident that virtually any combination of pressure and volume that was used to obtain spray droplets between 100 and 500 microns

MMD gave essentially complete control of leafhoppers. The control of flea beetle damage to the foliage was less definitive, but droplets of 500 microns MMD, formed at pressures as low as 25 p.s.i., and application rates as low as 20 gallons per acre, gave a degree of control essentially equal to that furnished by 100-micron drops, formed at pressures of 250 p.s.i. and application rates up to 160 gallons per acre.

In an experiment on the comparative control of potato flea beetle feeding on eggplant by spray droplets of different size, those of 500 microns MMD, formed when 35 gallons per acre were applied at 20 p.s.i., gave equally as good results as others of 120 microns applied at 240 p.s.i. Also, in the same experiment, droplets of 410 microns MMD, formed at a pressure of 20 p.s.i., gave as good control of the two-spotted spider mite as did others of 120 microns applied at a pressure of 240 p.s.i. In still another experiment, designed to study the relationship between spray droplet size and the control of the imported cabbage worm and cabbage loopers on cabbage, it was found that large drops in the range of 400 to 500 microns MMD, formed when the insecticide formulation was applied at 40 gallons per acre and 20 p.s.i., gave as good, or even better, control of both worms and loopers as did droplets of 115 to 175 microns formed when the same 40 gallons per acre were applied at 250 p.s.i.

The effect of varying the size of spray droplets on the control of some of the fruit and foliage diseases to which the tomato is subject in Ohio field culture was observed in a series of nine experiments conducted over a period of several years. During this interval (1954 to 1960) late blight (Phytophthora), anthracnose, and/or early blight (Alternaria) occurred in near-epidemic form in one or more instances. In 1955, when both early blight on the foliage and anthracnose fruit rot were comparatively severe, sprays applied with MMD values of 100 to 135 microns gave the better control of anthracnose on the fruit, whereas larger drops in the range of 300 to 400 microns gave as good or better control of early blight on the foliage as did the smaller drops. However, with an application rate of only 10 gallons per acre, the control of both diseases was comparatively poor, and this was the general experience with this rate of water use.

In 1957 and 1958, when late blight caused a considerable degree of defoliation and fruit rot in the tomato experimental plots, droplets as large as 300 to 500 microns MMD gave essentially as good control of both diseases as did smaller drops formed at higher pressures and gallonages.

Flat and hollow-cone spray patterns gave approximately the same degree of disease control when the remaining features of the application techniques were the same or similar. In these experiments on tomatoes the use of as few as 20 gallons of water per acre usually gave as good results in terms of disease control as did other application rates as high as 160 gallons.

In a 1961 experiment on sugar beets for the control of leaf spot (Cercospora) droplets as large as 500 microns MMD gave approximately as good results as did others as small as 100 microns. Flat and hollow-cone spray patterns gave essentially the same degree of disease control, with the former slightly the better, this in spite of the fact that the initial and weathered deposits of the copper compound used in the experiment were larger for the hollow-cone than the flat-pattern application. Also in these sugar beet experiments the initial and weathered deposits of copper were higher with low gallonage-low pressure applications (large spray droplets) than with high gallonages and pressures (small drops).

Thus, in final summary, the data obtained on disease and insect control when several different row crops were sprayed with droplet complexes of different mass median diameters indicated that those drops as large as 400 microns MMD, formed at application pressures as low as 30 to 50 p.s.i. and rates of water use as low as 20 to 40 gallons per acre, gave essentially as good results in most instances as did others of 100 to 150 microns MMD, formed at considerably higher pressures, and sometimes higher gallonages. Droplets as large as 500 microns MMD gave excellent control of several different insects on several different hosts, but were not quite the equal of smaller drops in disease control, except in one or two experiments in the control of tomato diseases. Also, application rates as low as 10 gallons per acre failed in most instances to give as good control as did 20 or more gallons per acre.

LITERATURE CITED

1. Behrens, R. 1957. Influence of various components on the effectiveness of 2,4,5-T sprays. Weeds 5: 183-196.
2. DallaValle, J. M. 1948 (Sec. Ed.). Micrometrics, The Technology of fine particles. Pitman Publishing Co., New York, N.Y.
3. Ennis, W. B., and R. E. Williamson. Influence of droplet size on effectiveness of low-volume herbicidal sprays. Weeds 11 (1): 67-72.
4. Hedden, O. K. 1960. Spray drop sizes and size distribution in pesticide sprays. Trans. Amer. Soc. Agric. Engineers 4 (2): 158, 159, 163.
5. Mullison W. R. 1953. Effect of droplet size on herbicidal effectiveness. Down to Earth 9 (2): p. 11.
6. Ogawa, J. M., and W. E. Yates. 1962. Effect of volume and variations in droplet size of spray applications from an air-carrier sprayer on the control of three almond diseases. Plant Dis. Reptr. 46 (8): 614.
7. Potts S. F. 1958. Concentrated spray equipment, mixtures and application methods. Dorland Books, Caldwell, N.J.
8. Sleesman, J. P., and J. D. Wilson. 1943. Comparison of fixed coppers and Bordeaux mixture in the control of insects and diseases of muck-grown Irish Cobbler potatoes. Ohio Agr. Exp. Sta. Bimo. Bull. 28: 173-183.
9. Smith, H. H. 1946. Quantitative aspects of aqueous spray applications of 2,4-dichlorophenoxyacetic acid for herbicidal purposes. Bot. Gaz. 107: 544-551.
10. Tilford, P. E. 1940. Ohio potato diseases. Ohio Agr. Exp. Sta. Bull. 615: 1-35.
11. Wilkes, L. H. 1961. Effects of nozzle types and spray application methods on cotton insect control. Trans. Amer. Soc. Agric. Engineers. 4 (2): 166-169.
12. Wilson, J. D. 1950. Concentrated vegetable sprays. Ohio Farm & Home Res. 35: 40-41.
13. Wilson, J. D. 1952. Low-gallonage fungicide sprays. Agric. Chemicals 7 (2): 40-41.
14. Wilson, J. D. 1953. Reduced volume, low pressure spraying of row crops in 1952. Proc. Ohio Veg. & Potato Growers' Assoc. 38: 25-32.
15. Wilson, J. D., and Orve Hedden. 1957. Droplet size versus control efficiency of fungicidal spray applications. Phytopathology 47: 37 (Abstr.)
16. Wilson, J. D., J. P. Sleesman, and Frank Irons. 1957. Control of foliage diseases and insects of potatoes. Ohio Agr. Exp. Sta. Res. Bull. 788: 1-114.
17. Wilson, J. D., and Frank Irons. 1959. Disease control using air-blast sprayers. Amer. Veg. Grower 7 (6): 9, 41.
18. Winter, H. F., and H. C. Young. 1950. The present status of concentrate orchard spraying. Proc. Ohio Hort. Soc. 103: 57-65.
19. Yeomans A. H. 1952. Influence of particle size on application of insecticidal sprays. Advances in Chemistry, Series No. 7: 56-59.
20. Yeomans, A. H., and E. E. Rogers. 1952. Factors influencing deposit of spray droplets. Jour. Econ. Entomology 46 (1): 57-60